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JAN 77 E L KRINITZSKY, D M PATRICK

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EARTHQUAKE INVESTIGATIONS AT THE DICKEY-LINCOLN SCHOOL DAMSITES, MAINE

by

Ellis L. Krinitzsky, David M. Patrick

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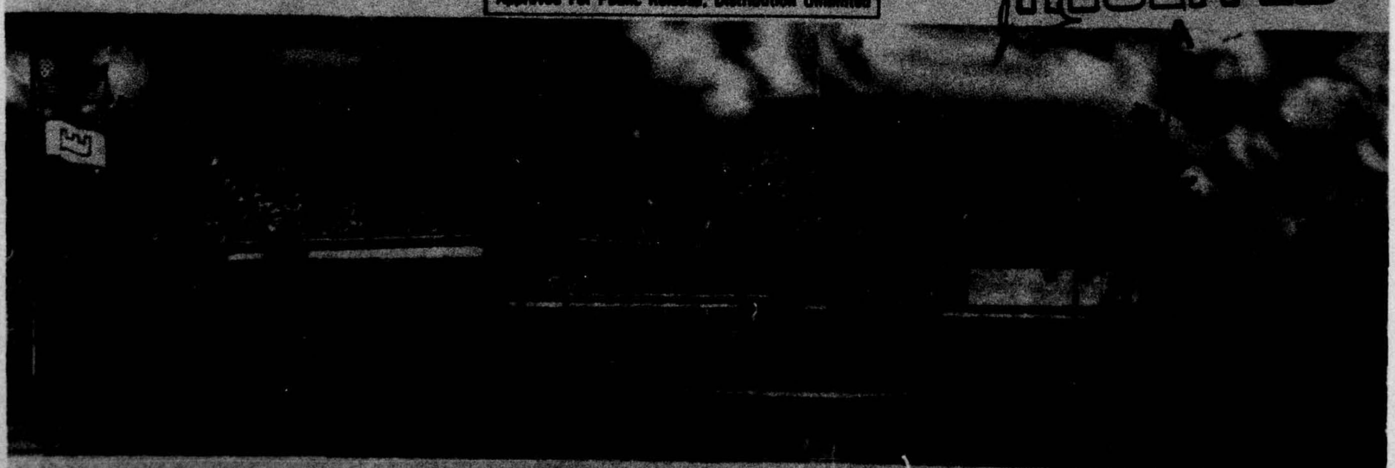
P. O. Box 631, Vicksburg, Miss. 39180

January 1977

Final Report



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The Dickey-Lincoln School damsites are less than 50 miles from an area along the St. Lawrence River which has experienced some of the most severe earthquakes in North America. A geological and seismological investigation was made of the region in order to determine the hazards from earthquakes at the damsites. No active faults were found in the general area of the damsites. The source area of potentially severe earthquakes was found to be restricted to a narrow band that follows the St. Lawrence River. This band

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was designated as Zone A. The boundary of Zone A is located 45 miles from the damsites. Zone B, with less seismic risk, borders Zone A and is 40 miles from the damsites. The damsites are situated in Zone C, which has the least seismic risk in the region. Zone D, with a level of seismic risk between that of Zones B and C, occurs 75 miles southeast of the damsites. The most severe ground motion at the damsites was interpreted to be from an earthquake in Zone A attenuated over a distance of 45 miles. Such movement is interpreted to have a peak acceleration of 0.35 g, a peak velocity of 65 cm/sec, and a peak displacement of 22 cm. The duration of shaking is estimated at 18 sec. Accelerographs are recommended for scaling in order to develop time histories of bedrock ground motion for dynamic analyses.

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PREFACE

The U. S. Army Engineer Waterways Experiment Station (WES) was authorized to conduct this study by the U. S. Army Engineer Division, New England, on 14 April 1975 by appropriation order FY 75 IOA No. 75-C-51.

The work was done and the report written by Dr. E. L. Krinitzsky, Chief, Engineering Geology Research Facility, with the assistance of Dr. David M. Patrick. The interpretation of air imagery and the flights over the study area were coordinated with studies being made at the U. S. Army Cold Regions Research and Engineering Laboratory, under Dr. H. L. McKim at Hanover, New Hamphsire. Fieldwork was done with the assistance of Mr. Roy Gardner of Allagash, Maine, who served as guide. Consultants for this study were Dr. David B. Slemmons of the University of Nevada in Reno and Dr. Otto W. Nuttli of St. Louis University in St. Louis, Missouri. Helpful comments on the manuscript were furnished by Mr. S. J. Johnson, Special Assistant, Soils and Pavements Laboratory, WES.

The project was under the general direction of Mr. Don C. Banks, Chief of the Engineering Geology and Rock Mechanics Division, and Mr. J. P. Sale, Chief of the Soils and Pavements Laboratory. COL G. H. Hilt, CE, and COL J. L. Cannon, CE, were Directors of WES during the conduct of this study and preparation of this report. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
square miles	2.589988	square kilometres
degrees (angular)	0.01745329	radians

EARTHQUAKE INVESTIGATIONS AT THE DICKEY-LINCOLN SCHOOL DAMSITES, MAINE

PART I: INTRODUCTION

General

1. The Dickey-Lincoln School damsites in northeastern Maine are less than 50 miles* from an area of intense earthquakes along the St. Lawrence River. The historic record, which dates back to 1638, includes over 100 earthquakes, a number of which were of notable severity. Consequently, the sites needed to be evaluated carefully for seismic risk.

Objective

2. This study was undertaken to provide a review of the tectonism, faulting, present activity of faults, effects of glacial loading and unloading, and the significance of the seismic history in the region. These aspects were evaluated in terms of the levels of seismic risk that they imply. The latest practices were used to determine design earthquakes and their appropriate ground motions for the bedrock at the damsites.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 6.

PART II: GENERAL GEOLOGY

Physiography

3. The Dickey and Lincoln School sites are in the New England Upland Subdivision of the New England Maritime Physiographic Province. The general relation of the sites to the St. Lawrence Valley, to the Canadian Shield, and to the structural grain of northern New England is shown in Figure 1.[1] The terrain in the general area of the sites is mantled with glacial drift and is gently rolling. Hilltops have approximate elevations of 1400 to 1700 ft msl and valley bottoms are 800 to 1000 ft msl. There are more highly elevated hills or mountains of which Hafey Mountain and Rocky Mountain are examples (see Figure 2).[2] Their elevations approach 2000 ft. These topographic highs are a result of greater resistance to erosion.

4. The major drainage system is the St. John River and its tributaries, the Black and Allagash Rivers. Generally, the overall character of the drainage is a result of continental glaciations with ponds, marshes, and misfit streams. Drainage alignment is irregular and may have been caused either by the disruption of drainage by glaciation or by structural controls in the bedrock.

5. The St. John, Black, and Allagash Rivers occupy valleys that contain deposits of glaciofluvial sand, gravel, and, occasionally, clay. The granular deposits along the St. John Valley appear to represent a valley train which resulted from the wasting of the last continental glacier. The largest streams have cut through the glaciofluvial deposits so that sand and gravel occur on the valley sides as high as 75 to 100 ft above the river level.

6. Stream terraces occur along the St. John River Valley and are developed at Lincoln School and farther downstream. In general, the terraces are irregularly developed. The occurrences of slump features and steep dips in these granular deposits suggest that the terrace material may have been in contact with glacial ice.

Stratigraphy

7. A schematic section of the rock sequences for the Dickey-Lincoln School sites is indicated by Section A-A' in Figure 3[3] (see location of section in Figure 1).

8. The knowledge of stratigraphy in this area is incomplete. Metamorphism, a lack of marker beds, faulting, glaciation, and thick forest cover have made the area difficult to interpret. This report has relied principally upon the work of Boudette et al.[2] for information on the geology. The discussion of the stratigraphy is here presented in terms of lithology as opposed to formational names because of a lack of detailed stratigraphic information.

9. Figure 3 illustrates the general geology of the area. The section consists of approximately 42,000 ft of metamorphosed sedimentary rocks including shale, slate, graywacke, metaquartzite, arkosic sandstone, and conglomerate. Shale and slate are the predominant rocks in the immediate vicinity of both sites. The geological ages range from Cambrian to Lower Devonian. The latter age is assigned to the shale and slate which outcrop at the proposed damsites. The fine-grained rocks are more highly metamorphosed than the coarser grained rocks; the highest metamorphism, excluding contact with igneous rocks, is that where chlorite has developed.

10. Igneous rocks include Devonian quartz monzonite and quartz latite, as well as greenstone and a metamorphosed andesite of Silurian age. The quartz latite is well exposed at Rocky Mountain. The andesite, greenstone, and quartz latite are exposed along the Rocky Mountain thrust fault (Figure 2).

11. Proceeding southeast from the St. Lawrence River toward the proposed damsites (approximately 50 miles) the sedimentary rocks become progressively younger. The rocks mapped in Quebec and northwest of the Dead Brook thrust are undifferentiated Cambrian and Ordovician slate, phyllite, graywacke, and metaquartzite. Some of the rocks exposed in the area northwest of the Dead Brook thrust are undifferentiated Paleozoic Rocks.

12. Ordovician slate, graywacke, feldspathic sandstone, and conglomerate occur on the northwest side (upper plate) of the Rocky Mountain thrust. These rocks have unconformable contacts with the older Cambro-Ordovician and younger Silurian rocks.

13. The Silurian system is represented by a sequence of slate, siltstone, graywacke, sandstone, and biostromal limestones. These rock units are of Upper Silurian age and generally exhibit gradational horizontal and vertical contacts. This sequence also contains the oldest igneous rocks: a metamorphosed andesite (greenstone) and quartz latite. These igneous rocks and the enclosing sedimentary types are exposed along the Rocky Mountain thrust. The igneous rocks are interpreted as extrusive lavas, although an intrusive interpretation could also be made.

14. Two sequences of rocks, separated by unconformity and both of Upper Silurian or Lower Devonian age, occur to the southeast of the Rocky Mountain thrust. These rock units consist of slate, phyllite, arkose, quartzite, and graywacke.

15. The youngest rock units are of Lower Devonian age and consist of slate, sandstone, graywacke, and metamorphosed basalt (greenstone) interpreted as extrusive. The sedimentary rocks are characterized by cyclical bedding and gradational horizontal and vertical bedding and gradational horizontal and vertical contacts. These rocks are exposed on the southeast side of the Rocky Mountain thrust and extend southeast of the Allagash River where they are mapped as undifferentiated Lower Devonian. The rocks underlying the proposed sites belong to this sequence.

Lithology

16. The sedimentary rocks have all been subjected to various degrees of metamorphism. The highest metamorphism near the sites is the chlorite which occurs west and north of the St. John and Little Black Rivers and in the drainage system near Dickey. Downstream and generally east of Dickey the rocks exhibit much less metamorphic alteration.

17. The fine-grained rocks exhibit well-developed foliation and cleavage and have been metamorphosed into slates and phyllites. The coarsest clastics are extremely hard and well indurated.

18. The rocks in the study area may be categorized as follows:

a. Shale, siltstone, slate, phyllite, argillite, and hornfels.

b. Arkose, graywacke, and conglomerate.

c. Sandstone, orthoquartzite, and quartzite (metaquartzite).

d. Quartz latite, andesite, and basalt.

e. Granodiorite and quartz monzonite.

Depositional History

19. The rocks at the sites resulted from deposition in a eugeosynclinal basin. This basin was probably very close to a source area to the southeast which was actively eroded and contributed fine and coarse clastic material. Some clastics were deposited as marine sediments; others were deposited in deltas and beaches. The poor sorting and heterogeneous composition of the rocks suggest tectonism and lack of stability in the source area. The organic population of the ancient sea was most likely sparse. Generally, coarse clastics do not present the most hospitable habitat for marine life; however, graptolites are preserved in the finer grained shales and slates.

PART III: TECTONIC HISTORY

Orogenies

20. Orogenic events have occurred as follows:

a. Taconian. The earliest orogeny was the Taconian. This event occurred during late Ordovician or Silurian time and resulted in the development of large overthrust sheets which moved slices of geosynclinal sediments from the southeast toward the shield area to the northwest. This orogeny is marked by an unconformity between deformed Ordovician and older rocks, and the younger Silurian strata.

b. Acadian. The Acadian orogeny occurred during middle and late Devonian time and resulted in faulting, folding, and extensive intrusive igneous activity, of which folding and faulting are the most characteristic in the study area. This orogeny was the last major tectonic event in the Northern Appalachian Deformed Belt. Although Upper Paleozoic rocks are absent in the study area, due either to nondeposition or erosion, they do occur in Gaspé (see Figure 1) where they exhibit only minor deformation.

c Triassic events. After the Acadian orogeny and possibly after late Paleozoic deposition, the Northern Appalachian Deformed Belt was uplifted and experienced considerable erosion. During Triassic time, this region was subjected to tensional forces which resulted in normal faulting and the development of elongate grabens. These fault-bound structures received clastic sediments from the adjacent mountains which were then being eroded. Associated with the sedimentation in the grabens were basaltic intrusions and flows. Although the boundary faults along the graben margins predate the sediments, the sediments themselves have been affected by faulting and warping. The known Triassic grabens nearest the study area are in the Bay of Fundy and in the Gulf of Maine (Ballard and Uchupi[4]).

Structural Deformation

21. The type of structural deformation exhibited in the study area is one of both folding and faulting. The axes of the folds generally run from southwest to northeast as do the strikes of the major faults. The dips of the beds are quite steep and it is uncommon to

find bedding planes with dips less than 50 deg.

Folding

22. The study area lies between two broad fold axes: an anticlinal axis trending northeast-southwest in Quebec to the northwest and a synclinal axis of similar strike lying to the southeast. The folds occurring in the study area have been superimposed on the limbs of these larger folds.

Faulting

23. The faults mapped by Boudette et al.[2] (Figure 2) include two major overthrust faults, Rocky Mountain and Dead Brook; two reverse faults, Big Black River and Jones Brook; several small faults associated with the thrust faults; and a presumed fault, the Hunnewell, striking approximately parallel to the St. John River near both sites (see Figure 2). The data on the major faults are summarized in Table 1.

24. The faults listed above have been identified by Boudette et al. on an inferential basis. The criteria for classifying these structural features as faults are:

a. Photolinear offsets: Includes the discontinuity of lithologic units and displacement along strike as determined by aerial photographs.

b. Stratigraphic truncation: Based upon the truncation, disappearance, or apparent pinching out of significant thickness of a stratigraphic interval along a photolinear. Folding and/or unconformity may be offered as alternate explanations for the truncation, but Boudette et al. believe that faulting is the most realistic interpretation.

c. Stratigraphic juxtaposition: Related to stratigraphic truncation. Involves the juxtaposition of two lithologic units and the absence of an intermediate lithologic unit.

d. Lineaments: Photolinears, not related to topography, strike of bedding, or folding. Used for the mapping of the continuation of faults identified by other means. In the case of Hunnewell, was used for primary identification.

e. Ground evidence: Ground observation of faulted contacts. Best criterion. Generally, this means was not useful in the study area because of ground cover. Fault contacts are evident on Rocky and Hafey Mountains.

Table 1

Major Faults in the Project Area

Fault (See Figure 2)	Minimum Mapped Length, miles	Fault Type	Probable Stratigraphic Age	
			Max	Min
1. Rocky Mountain	56	Major overthrust	Lower Devonian	Lower Devonian
2. Dead Brook	16	Major overthrust	Upper Silurian or Lower Devonian	Lower Devonian
3. Big Black River	14	Subsidiary reverse	Lower Devonian	Lower Devonian
4. Jones Brook	22	Subsidiary reverse	Upper Silurian or Lower Devonian	Lower Devonian
5. Hunnewell	29	Unknown	Lower Devonian	Lower Devonian

Rocky Mountain overthrust

25. This fault is the longest and one of the most significant structures in the study area. The length shown in Table 1 is only for the mapped segment in the western part of the study area, and it is possible that the fault continues into Canada where other faults have been mapped. The relative movement on the Rocky Mountain overthrust was northwest to southeast. The amount of lateral or strike-slip movement is unknown. The ages of the rocks cut by the Rocky Mountain overthrust range from Middle Ordovician to Lower Devonian.

Dead Brook overthrust

26. This fault exhibits a relative movement similar to the Rocky Mountain overthrust and cuts Cambro-Ordovician and Upper Silurian or Lower Devonian rocks.

Big Black River fault

27. This is a reverse fault associated with the Rocky Mountain overthrust in the southwestern part of the study area. The fault cuts Middle Ordovician and Lower Devonian rocks.

Jones Brook fault

28. This is a reverse fault associated with the Rocky Mountain overthrust in the northwestern portion of the study area. The fault cuts Middle Ordovician and Upper Silurian or Lower Devonian rocks.

Hunnewell lineament or fault

29. This structure is the largest inferred fault in the vicinity of both sites. The criterion for recognition was the lineament seen in aerial photographs. Boudette et al.[2] considered that the magnitude of the lineament and its truncation of bedding, folds, and topography were sufficient evidence to call the structure a fault. The location of the fault, within the Lower Devonian sequence, and ground cover have contributed to the absence of ground evidence for the existence of the fault.

PART IV: GLACIATION

30. During Pleistocene time the study area was covered by great thicknesses of glacial ice. The exact thickness of the ice sheet is unknown; however, Flint[5] (page 319) presents data indicating that the ice sheet may have been as much as 4700 ft thick in the Mt. Katahdin area to the south. The effects of the ice sheet were erosional, depositional, and tectonic.

31. The erosional effect of the ice, which moved from the northwest to southeast, was to temper the existing topography. There are no indications of deep glacial scouring although glacial striae are abundant on the harder rocks throughout the area. The absence of significant differential glacial erosion may be due to the fact that the direction of glacial movement was normal to the strike of the rocks.

32. The depositional features include a relatively thin veneer of ground moraine which covers most of the area. The ground moraine consists primarily of poorly sorted till and subordinate sand and gravel lenses. The till is usually quite thin and averages a few feet thick. Boudette et al.[2] indicate that the till may be locally quite deep and suspect that thicker deposits may occur on the northwest sides of hills facing the glacial advance. Glaciofluvial deposits resulting from the melting of the last ice sheet are also present throughout the area. These deposits include valley train or outwash along the St. John River and various other stratified deposits thought to be either kames, lacustrian deposits, or crevasse fillings.

33. The presence of such great thicknesses of glacial ice also resulted in a regional tectonic effect. This effect was crustal warping under the load of ice. The evidence for the amount of crustal warping has been derived from tide gage records and from elevations of Pleistocene tidal strandlines (Flint,[5] pages 249-255). Data indicate that northern Maine is rising or rebounding at the rate of approximately 30 cm/100 yr. The highest Pleistocene strandline in Maine is approximately 450 ft above present-day sea level, indicating that at the strandline the surface has rebounded 450 ft.

PART V: EARTHQUAKE ACTIVITY

Historic Earthquakes

34. Historic earthquakes in northern New England and adjacent parts of Canada are listed in Table 2. Corresponding locations are shown in Figure 4. The data were tabulated from publications of the Dominion Observatory (see Smith[6,7]) in Ottawa, Canada (now the Department of Energy, Mines and Resources); the Earthquake History of the United States through 1970 (Coffman and von Hake);[8] United States Earthquakes 1971 (Coffman and von Hake[9]); listings of the National Earthquake Information Service (NEIS) to 1975; and Hadley and Devine.[10] The Hadley and Devine earthquakes are those which occur on their seismotectonic map where they are credited to the Dominion Observatory and to the National Oceanic and Atmospheric Administration (NOAA). The accreditation was found to be erroneous when discrepancies were seen in comparing the Hadley and Devine events with those of a computer printout furnished by the NOAA Environmental Data Service. Carl von Hake* of NOAA advised us that the questioned events were not known to NOAA and are probably from USGS noninstrumental data belonging to Hadley and Devine. The questioned events are denoted by a special symbol in Figure 4 and are credited to Hadley and Devine.[10] They are not listed in Table 2 since, at the time of this writing, no further information had been received from the USGS.

35. The questioned earthquakes might be important as one of them lies only 20 miles from Dickey damsite. Two others are a little over 30 miles away. Yet, since they are probably not instrumental records and they are very small events reported from a sparsely populated region, their locations may be very inaccurate. The locations are not likely to represent epicenters and there is the possibility that they are errors altogether.

36. The earthquakes are expressed as intensities according to the

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* Personal communication, 5 June 1975.

Table 2

Historic Earthquakes in Northern New England and Adjacent Parts of Canada (1638 to 1975)

Year	Date	Time EST	Locality	Coordinates N. Lat. Deg.	Coordinates W. Long. Deg.	Intensity MM	Source Data DO	Source Data NEIS	Source Data EHUS
1638	6 Jun	1900	St. Lawrence Valley	46.5	72.5	IX	x	x	
1661	10 Feb	1900	St. Lawrence Watershed	45.5	73.0	VII	x		
1663	5 Feb	1730	St. Lawrence River Valley region	47.6	70.1	X	x		x
1665	24 Feb	--	La Malbaie, Quebec	47.8	70.0	VIII	x		
1668	13 Apr	0800	Near Isle-aux-Grues	47.1	70.5	VI	x		
1732	16 Sep	1600	Montreal, Quebec	45.5	73.6	IX	x	x	
1791	6 Dec	2000	St. Lawrence River Valley	47.4	70.5	VIII	x		
1810	10 Nov	0215	--	43.0	70.9	VI		x	
1817	22 May	2000	Central Maine	46.0	69.0	VI		x	
1824	9 Jul	--	Providence of New Brunswick, Canada	46.5	66.5	V	x		
1831	May 7-8	Night	St. Lawrence River Valley	47.3	70.5	VII	x		
1831	14 Jul	--	St. Lawrence River Valley	47.6	70.1	VII	x		
1842	9 Nov	--	St. Lawrence River Valley	46.0	73.2	VI	x		
1847	8 Jan	1500	Felt near Grafton Harbour, Ontario	44.0	70.0	III	x		
1848	1 Feb	--	Felt at Yarmouth and Shelburne	43.5	65.5	III	x		
1848	6 Nov	0515	Felt at Grand Is-St. Lawrence River	47.6	69.9	II	x		
1853	Jul	--	Province of Quebec	47.5	70.0	III	x		
1855	4 Feb	--	Bay of Fundy	44.8	66.2	VI	x		
1855	8 Feb	0630	Near Moncton, N. B.	46.0	64.5	VII	x		
1855	Jun	--	SE of Granville Mountains N.S.	44.7	65.5	IV	x		
1858	17 May	1500	Richmond, Compton, Sherbrooke, Quebec	45.5	72.1	IV	x		
1860	17 Oct	0600	Canada, St. Lawrence River Valley	47.5	70.0	VIII-IX	x	x	x
1861	Oct	0900	Ile Jesus, Quebec	45.6	73.7	V	x		
1867	18 Dec	0800	W. Vermont	44.0	73.0	V	x	x	
1869	22 Oct	1100	Bay of Fundy	45.0	66.2	VIII	x	x	x
1870	8 Feb	--	Bay of Fundy	44.1	67.1	VI	x		
1870	20 Oct	1625	Baie-St. Paul, Quebec	47.4	70.5	IX	x	x	x
1871	9 Jan	--	Kamouraska, Quebec	47.5	70.1	V	x		
1872	10 Jan	0054	Canada and to the south	47.5	70.5	VII	x	x	x
1872	18 Nov	1900	--	43.2	71.6	V	x		
1873	30 Sep	0650	Felt at Montreal, Quebec	45.5	73.2	IV	x		
1874	28 Feb	0340	SE Maine	44.8	68.7	V		x	x
1877	4 Nov	0656	NE New York state	44.5	74.0	VII	x	x	
1879	11 Jun	--	Felt at Montreal	45.6	73.6	IV	x		
1880	6 Sep	0030	Felt at Montreal	45.2	73.8	IV	x		
1881	21 Jan	0240	Bath, Maine	44.0	70.0	V		x	x
1881	31 May	0330	Felt in Quebec	47.1	70.4	II	x		
1881	1 Oct	0140	Felt in Quebec	47.6	70.2	IV	x		
1882	19 Dec	2220	New Hampshire	43.2	71.4	V		x	x
1882	31 Dec	2200	New Brunswick coast	45.0	67.0	VI	x		x
1882	23 Nov	0030	South New Hampshire	43.2	71.7	V-VI			x
1883	1 Jan	0030	--	45.0	67.0	V		x	
1884	23 Nov	0530	--	43.2	71.7	VI		x	
1885	6 Apr	0900	Felt in Quebec	47.5	70.2	III	x		
1885	Jun	1000	Felt in Southern Head, N. B.	45.1	66.1	IV	x		
1886	12 Aug	a.m.	Felt in Quebec	46.0	74.0	IV	x		
1888	7 Dec	0925	Felt in Quebec	48.5	68.7	IV	x		
1891	2 May	0010	South New Hampshire	43.2	71.6	V		x	x
1893	27 Nov	1150	Felt over Quebec, New England	45.5	73.3	VII	x		
1894	17 Apr	1115	Felt at Montreal	45.6	73.3	IV	x		
1896	23 Mar	0056	Maine and New Brunswick	45.2	67.2	IV-V	x	x	x
1897	26 Jan	a.m.	Felt at Deer Islands, N. B.	44.9	66.9	III	x		
1897	28 Jan	2100	Felt at Southern Head, N. B.	44.5	66.8	IV	x		
1897	14 Feb	2100	Felt at Grand Manan Is, N. B.	44.7	66.8	III	x		
1897	23 Mar	1800	Near Montreal	45.5	73.6	VII	x		
1897	27 May	2000	Near Lake Champlain	44.5	73.5	VI	x		
1898	11 Jan	0200	Felt at Grand Manan Is, N. B.	44.7	66.8	IV	x		
1898	17 Sep	1550	--	44.3	69.1	V		x	
1904	21 Mar	0600	SE Maine	45.0	67.2	VII		x	x
1905	15 Jul	1000	Maine and New Hampshire	44.3	69.8	V		x	x
1905	30 Aug	1040	--	43.0	71.0	V		x	
1906	31 Dec	--	Charlevoix Co., Quebec	47.7	70.8	III	x		
1908	13 May	2400	Felt in 3 Co.'s N-S	44.0	65.8	V	x		
1908	8 Aug	0700	Hartland, N. B.	46.3	67.6	VI	x		
1909	14 Apr	Night	St. John, N. B.	45.4	66.4	III	x		
1910	23 Jan	0115	--	43.8	70.4	V		x	
1910	Feb	--	St. Lawrence Valley	48.0	70.0	VI	x		
1910	25 Oct	0430	Kamouraska Co., Quebec	47.6	69.8	V	x		
1912	11 Dec	1015	West of Eastport, Maine	45.0	68.0	VI	x	x	x

(Continued)

Note: Source Data:
1. DO - Dominion Observatory, Ottawa.[6,7]
2. NEIS - National Earthquake Info. Service, USGS, 1975.
3. EHUS - "Earthquake History of the United States," Pub. 41-1, NOAA, 1970, 1971.[8]

Table 2 (Continued)

Year	Date	Time EST	Locality	Coordinates N. Lat. Deg.	Coordinates W. Long. Deg.	Intensity MM	Source Data DO	Source Data NEIS	Source Data EMUS
1913	10 Aug	0515	Lake Placid, New York	44.0	74.0	V		x	x
1914	13 Jan	0800	Calais, Maine and N. B.	45.1	67.2	V	x	x	
1914	14 Feb	0430	N. of Ste. Emélie, Quebec	46.4	73.6	V	x		
1914	22 Feb	0015	--	45.0	70.5	V		x	x
1916	5 Jan	1355	--	43.7	73.7	V		x	
1916	3 Feb	0426	--	43.0	74.0	V		x	
1916	29 Feb	0015	Quebec City, Quebec	46.8	70.9	IV	x		
1916	2 Nov	0232	--	43.3	73.7	V		x	
1917	11 Jun	2100	S. shore of the St. Lawrence River	49.0	68.0	V	x		
1918	21 Aug	0412	S. Maine	44.2	70.6	V.I		x	x
1919	26 Oct	0528	N. shore of the St. Lawrence River	47.6	70.0	IV	x		
1921	10 Oct	0800	Eastport, Maine	44.8	67.0	IV	x		
1922	2 Jul	1725	Central New Brunswick	46.5	66.6	VI	x		
1924	4 Mar	1415	N. of La Malbaie, Quebec	47.8	70.2	V	x		
1924	30 Sep	0852	W. of La Malbaie, Quebec	47.6	69.7	VII-VIII	x		x
1925	28 Feb	2119	St. Lawrence River Valley	47.6	70.1	IX	x		
1925	1 Mar	0219	--	48.3	70.8	VIII		x	
1925	6 May	0414	Felt at Quebec City, Quebec	46.9	71.6	III	x		
1925	20 Jul	early	N. and NW of Quebec City	46.9	71.3	III	x		
1925	9 Oct	1355	SE New Hampshire and Maine	43.7	70.7	VI	x	x	x
1925	19 Oct	0705	Felt at Montreal	47.0	73.0	V	x		
1926	19 Feb	1520	St. Lawrence Valley	47.7	71.0	IV	x		
1926	21 Feb	1655	St. Lawrence Valley	47.6	70.9	IV	x		
1926	28 Aug	2100	W. Maine	44.7	70.0	V		x	x
1926	21 Sep	0630	Felt at St. Simeon, Quebec	48.0	70.5	IV	x		
1926	24 Nov	1430	Felt at Eastport, Maine	45.0	67.5	IV	x		
1927	24 Jul	1756	St. Lawrence Valley	47.3	71.0	V	x		
1927	9 Aug	0408	--	43.3	71.4	V		x	
1928	27 Jan	--	N. of La Malbaie, Quebec	48.0	70.2	IV	x		
1928	19 Mar	1907	Champlain Co., Quebec	46.6	72.5	II	x		
1928	25 Apr	2338	Berlin, N. H.	44.5	71.2	VI		x	x
1928	20 Nov	0230	NW of Eastport, Maine	45.0	67.2	IV	x	x	
1928	25 Dec	0200	--	46.2	67.9	--		x	
1929	29 Mar	--	--	45.2	67.3	--		x	
1929	11 May	0930	W. Sherbrooke, Quebec	45.2	71.5	IV	x		
1930	4 Jan	1430	Blackville, N. B.	46.7	65.8	(V)	x		
1930	19 Jun	1207	NE of Sherbrooke, Quebec	45.7	71.2	(IV)	x		
1930	13 Jul	0453	Near Kamouraska, Quebec	47.5	69.9	(III)	x		
1930	8 Oct	0109	Felt at Riviere Bersimis	48.9	68.7	(IV)	x		
1930	16 Oct	0035	Felt at Millerton, N. B.	46.9	65.6	II	x		
1930	13 Nov	0600	--	45.0	69.2	--		x	
1930	13 Dec	2318	Felt at Murray Bay, Quebec	47.6	70.2	(IV)	x		
1930	25 Dec	2208	Near La Malbaie, Quebec	47.6	70.2	(V)	x		
1931	8 Jan	0014	Near La Malbaie, Quebec	47.6	70.2	(VII)	x		
1931	24 Jan	1220	Near La Malbaie, Quebec	47.5	70.6	(IV)	x		
1931	9 Apr	--	Deer Is, N. B.	45.0	67.0	III	x		
1931	20 Apr	1956	--	43.4	73.7	VII		x	
1931	7 Aug	--	Digby	44.6	65.7	IV	x		
1931	14 Nov	1402	E. of Baie-St. Paul, Quebec	47.2	70.1	(IV)	x		
1932	27 Jul	0030	Felt at Baie-St. Paul, Quebec	47.5	70.5	I-II	x		
1932	2 Aug	0738	Felt at Baie-St. Paul, Quebec	47.5	70.5	(III)	x		
1932	26 Nov	0502	NW of Baie-St. Paul, Quebec	47.6	70.6	(III)	x		
1933	11 Jan	2332	Felt at Baie-St. Paul, Quebec	47.5	70.5	III	x		
1933	25 Feb	0943	Near St. Pacome, Quebec	47.5	70.0	(IV)	x		
1934	15 Mar	--	Southern Nova Scotia	43.5	65.5	III-IV	x		
1934	17 Mar	0258	Adirondack Mountains, NY	44.5	73.9	VI	x	x	

(Continued)

Note: Intensity: () indicates interpolated.
\+ Indicates by NOAA as V.

Table 2 (Continued)

Year	Date	Time EST	Locality	Coordinates N. Lat. Deg.	Coordinates W. Long. Deg.	Intensity MM	Source Data DO	Source Data NEIS	Source Data EHUS
1936	29 Mar	0049	St. Lawrence River Valley	47.3	70.2	(V)	x		
1936	9 Nov	0246	--	43.6	71.4	V		x	
1937	19 Jan	2058	Felt at Baie-St. Paul, Quebec	47.5	70.5	(II)	x		
1937	24 Sep	0646	Felt in Montreal, Quebec	45.6	73.6	(II)	x		
1937	30 Sep	0758	NE of Rothesay, N. B.	45.5	65.9	(VI)	x		
1938	15 Jun	0508	NE of Napadogan, N. B.	46.5	66.8	III-IV	x		
1938	22 Aug	0748	Vicinity of Bangor, Maine	44.7	68.8	V			x
1939	24 Jun	1720	N. Seven Falls, Quebec	47.9	70.9	(VI)	x		
1939	19 Oct	1154	NE of La Malbaie, Quebec	47.8	70.0	VI		x	x
1939	27 Oct	0136	--	48.0	70.4	--		x	
1939	8 Dec	0118	Near Chicoutimi R., Quebec	47.9	71.5	(IV)	x		
1939	25 Dec	1029	NW of La Malbaie, Quebec	48.0	70.5	(V)	x		
1940	13 Apr	0813	NW of Baie-St. Paul, Quebec	47.7	70.7	(IV)	x		
1940	16 May	1400	W. of L'Assomption, Quebec	45.8	73.1	(IV)	x		
1940	11 Sep	0107	NE of Quebec City, Quebec	47.0	71.1	(IV)	x		
1940	13 Oct	1950	NW of Clermont, Quebec	48.0	70.5	(VI)	x		
1940	12 Dec	0727	Lake Ossipee, N. H.	43.7	71.5	VII	x	x	x
1940	24 Dec	1343	--	43.8	71.3	VII		x	
1941	6 Sep	1704	Felt at Baie-St. Paul, Quebec	47.5	70.5	(IV)	x		
1941	6 Oct	1634	NW of Baie-St. Paul, Quebec	47.6	70.7	(V)	x		
1942	5 Sep	1430	NW of Quebec City, Quebec	47.0	71.5	(III)	x		
1943	14 Jan	2132	Dover, Foxcroft area, Maine	45.3	69.6	V		x	
1943	8 Jun	early	Yarmouth Co., N.S.	43.7	65.7	III	x		
1943	25 Sep	0553	NW of Baie-St. Paul, Quebec	47.5	70.6	(IV)	x		
1943	28 Sep	1630	St. Lawrence River Valley, Quebec	47.2	70.4	(IV)	x		
1943	6 Nov	0006	St. Lawrence River Valley, Quebec	47.4	70.0	(IV)	x		
1944	5 Feb	1238	Baie-St. Paul, Quebec	47.4	70.5	(V)	x		
1944	6 Jun	0600	Bathurst, N. B.	47.5	65.6	III	x		
1944	9 Jun	1519	St. Lawrence River Valley	47.2	70.2	(IV)	x		
1944	14 Oct	1326	St. Lawrence River	48.5	67.0	(V)	x		
1945	18 Jun	1520	NE of Quebec City, Quebec	47.1	71.0	(VI)	x		
1945	9 Oct	1318	NW of Baie-des-Rochers, Quebec	48.0	70.0	(VI)	x		
1946	17 Jan	0805	NW of Baie-Comeau, Quebec	49.0	68.1	(V)	x		
1946	21 Apr	0506	NE of Montreal, Quebec	45.7	73.3	(IV)	x		
1946	1 Sep	0439	Jacques Cartier River, Quebec	47.3	71.5	(IV)	x		
1946	26 Sep	2119	S. of Deschaillons, Quebec	46.5	72.1	(IV)	x		
1947	2 Jan	1815	Ste. Anne de Beaupre, Quebec	47.0	70.9	III	x		
1947	2 Feb	1650	W. of Malbaie, Quebec	47.6	70.5	(V)	x		
1947	29 Mar	1229	St. Lawrence River	47.4	70.1	(V)	x		
1947	22 Oct	0937	NW of Baie-St. Paul, Quebec	47.5	70.8	(IV)	x		
1947	28 Dec	1958	Dover-Foxcroft, Maine	45.2	69.2	V		x	x
1948	1 Jan	1834	SE of Seven Falls, Quebec	47.3	70.5	(VI)	x		
1948	7 May	1202	NNE of Montreal, Quebec	45.8	73.6	(V)	x		
1948	9 Jun	0304	SSW of Montreal, Quebec	45.3	73.9	(IV)	x		
1948	13 Nov	1650	St. Paul-de-Montminy, Quebec	46.4	70.3	(IV)	x		
1949	5 Oct	0234	SW Maine	44.8	70.5	V		x	x
1949	30 Oct	2051	Near Parisville, Quebec	46.5	72.1	(IV)	x		
1950	4 Aug	0645	St. Lawrence River	47.3	70.2	(III)	x		
1951	25 Jul	0023	Jacques Cartier River, Quebec	47.1	71.3	(IV)	x		
1951	6 Nov	1755	U. S. - Canada Border	45.00	73.5	(IV)	x		
1952	3 Feb	0233	E. of Quebec City, Quebec	46.9	70.5	(III)	x		
1952	26 Feb	0057	Ste. Apolline, Quebec	46.7	70.2	(IV)	x		
1952	30 Mar	1311	St. Lawrence River	47.8	69.9	(V)	x		
1952	19 Apr	0251	W. of Baie-St. Paul, Quebec	47.5	70.5	(IV)	x		
1952	14 Oct	2204	South Central Canada, Quebec	47.9	69.8	V	x	x	x
1953	28 Nov	1547	St. Maurice River Valley	45.9	73.1	(III)	x		
1954	7 Feb	2024	Pointe-au-Pic, Quebec	47.7	70.2	(IV)	x		
1954	21 Feb	0900	NNW of St. Urbain, Quebec	47.6	70.6	(IV)	x		
1954	30 Jun	0741	St. Cyrille-Ste. Félicité, Quebec	47.0	70.1	(IV)	x		
1955	1 Feb	1240	N. of Baie-St. Paul, Quebec	47.6	70.5	(V)	x		
1955	7 Oct	1810	SW of Montreal	45.2	73.9	(IV)	x		
1955	20 Oct	2058	Portneuf R., Quebec	48.9	70.2	(III)	x		
1955	26 Nov	0650	Close to St. Gabriel, Quebec	46.3	73.3	(II)	x		
1956	30 Jan	0943	Felt N. of Quebec City, Quebec	47.0	71.1	(IV)	x		
1956	12 May	0040	SW of Kiskisink, Quebec	47.9	72.3	(II)	x		
1956	10 Oct	0552	St. Lawrence River	47.3	70.3	(III)	x		
1956	27 Oct	1440	St. Lawrence River Valley	48.2	69.0	(IV)	x		
1957	19 Feb	1833	NW of Tadoussac, Quebec	48.4	69.9	(IV)	x		
1957	4 Apr	1140	Near Coast of Maine	43.6	69.8	VI		x	x
1957	4 Aug	1241	E. of Juniper, N. B.	46.5	67.1	(IV)	x		

(Continued)

Table 2 (Concluded)

Year	Date	Time EST	Locality	Coordinates N. Lat. Deg.	Coordinates W. Long. Deg.	Intensity MM	Source Data DO	Source Data NEIS	Source Data EHUS
1957	6 Aug	2350	Near Baie-St. Paul, Quebec	47.3	70.4	(V)	x		
1957	17 Aug	0130	NW of Lac-Frontiere, Quebec	46.7	70.1	(IV)	x		
1957	9 Oct	1417	NW of Tadoussac, Quebec	48.4	69.9	(III)	x		
1957	13 Nov	2049	NW of Sault-au-Moulton, Quebec	48.7	69.6	(IV)	x		
1958	23 Mar	2204	SE of McAdam, N. B.	45.5	67.1	(IV)	x		
1958	18 Jul	2356	St. Lawrence River Valley	46.6	71.4	(III)	x		
1958	27 Jul	0858	St. Lawrence River Valley	47.3	70.3	(III)	x		
1958	8 Aug	2215	Riviere Malbaie, Quebec	47.9	70.3	(V)	x		
1958	12 Aug	0322	NW of Sault-au-Mouton, Quebec	48.6	69.3	(IV)	x		
1958	11 Sep	1750	W. of Sault-au-Mouton, Quebec	48.6	69.7	(IV)	x		
1958	29 Sep	1045	St. Lawrence River	48.3	69.2	(IV)	x		
1958	30 Sep	0014	E. of Beauharnois, Quebec	45.1	73.7	(IV)	x		
1958	23 Dec	2314	NE of Ste. Félicité, Quebec	46.9	69.8	(IV)	x		
1959	16 Apr	1636	SE of Bonsecours, Quebec	47.1	70.3	(IV)	x		
1959	14 May	1424	S. of Bonsecours, Quebec	47.0	70.3	(II)	x		
1959	22 Aug	0352	St. Lawrence River	46.9	70.8	(III)	x		
1962	10 Apr	1430	Vermont	44.1	73.1	V		x	x
1963	4 Dec	2132	--	43.6	71.5	V		x	
1964	26 Jun	1204	Near Warner, N. H.	43.3	71.9	VI		x	x
1966	24 Jul	2100	--	44.5	67.6	V		x	
1966	23 Oct	2305	--	43.0	71.8	V		x	
1967	1 Jul	1409	Kennebec Co., Maine	44.9	69.9	V		x	x
1967	1 Jul	1556	--	44.4	69.9	V		x	
1968	19 Oct	1037	--	45.4	74.0	V		x	
1973	15 Jun	0109	--	45.3	70.9	V		x	

Modified Mercalli (MM) scale of 1931. An abbreviated form of the scale is shown in Figure 5.

Distribution of Earthquakes

37. The geographic distribution of historic earthquakes can be observed in Figure 4.

38. In the Dickey-Lincoln School area, there are no historic earthquakes for a radius of 20 miles. Within a radius of 20 to 40 miles, there are four events. All are of MM intensity of II to IV. Three of the four are questionable events, attributed to Hadley and Devine.[10]

39. The most important concentrations of earthquake activity occur in the St. Lawrence Valley. There is a trend which follows the St. Lawrence River but it is discontinuous. The greatest concentration is immediately west of Rivière du Loup. An MM intensity X has occurred there, as have three intensity IX's, three VIII's, and nearly a hundred events altogether. The abundance of earthquakes, from large to small, defines this area as one of very high seismic risk.

Relation to Contemporary Intraplate Tectonics

40. The St. Lawrence seismic belt occurs approximately along a portion of the boundary between the ancient crystalline rocks of the Canadian Shield and the sedimentary rocks that are developed south of the St. Lawrence River (compare Figures 1 and 4). The boundary coincides with an extension of Logan's Line. Logan's Line to the southwest, particularly in New York State, is a major thrust fault which forms the boundary between folded and faulted sedimentary rocks to the east and the relatively flat-lying and undisturbed sedimentary rocks to the west. Along the St. Lawrence east of Quebec City, Logan's Line separates the deformed sedimentary series so that their boundary lies almost in contact with the crystalline rocks of the Canadian Shield.

41. The question comes up whether the seismic belt in the St. Lawrence is part of a larger trend and has developed as an intraplate

boundary. Further, what geographic pattern or patterns do such a boundary have? Woollard[11] postulated a seismic trend along the full length of the St. Lawrence River and which extended as far as Arkansas. Smith[7] postulated a northwest to southeast trend (see Figure 6) which extends from the Kelvin Seamount Chain through the vicinity of Boston and through Montreal. In the area east of Quebec City there exists the possibility of a parallel but shorter trend that would cross the main St. Lawrence trend (see Figure 4). An examination of the intensity levels of the earthquakes shows that the severe events (those to IX and X) occur in a narrow belt along the St. Lawrence. There is a rapid falling off in the maximum intensity of events of V to VI adjacent to this belt. Beyond, the values are II to IV. A cross trend is not justified by the sizes of the events. Probably most of the events would bunch together in a narrow belt along the St. Lawrence were there better control for their locations.

42. The trend along the St. Lawrence is all that one can relate to intraplate tectonics. However, it relates to large global movements only in a most general and most uncertain way. The St. Lawrence trend is not defined in this area by known active faults.

Relation to Geologic Structures

43. Historic earthquakes in this area can be related to geologic structures in a general way, as was mentioned in the discussion of intraplate boundaries. However, no earthquakes have been related to specific structures since the epicentral locations are inexact and there have been no fault movements, recognizable at the surface, that have accompanied historic earthquakes.

44. The aeromagnetic map of northern Maine (Zeitz et al.[12]) is based on sparse data in the area of the damsites. However, in Maine in the general area of the damsites and within a 40-mile radius, there are no suggestions of significant anomalies. In the adjacent portion of Canada, toward the St. Lawrence, the aeromagnetic maps (Baie-St. Paul[13] and Edmundston[14] quadrangles of the Geological Survey of Canada) again

show an absence of significant anomalies. The contours become more closely spaced only within about 5 miles of the shore of the St. Lawrence River. This change in contours coincides in a general way with down-dropped blocks that have contributed to the formation of the St. Lawrence estuary. These blocks have been sculptured by erosion, and alluvial drowning has covered them in all but their highest portions. An example of their surface appearance is seen in Figure 7, which shows an extensive area of alluvial drowning along the border of the St. Lawrence about halfway between Quebec and Rivière du Loup. This is adjacent to the area of considerable earthquake activity noted in Figure 4.

45. The area bordering the St. Lawrence is too masked with alluvium to reveal any details of the tectonism that accompanied a settlement that most likely is continuing to occur.

46. The glacial advance over this area has been discussed. The area is still participating in a rebound that resulted from the removal of the weight of ice. Rebound from glaciation would not explain major earthquakes because those require concentrated stresses of a very large order. However, small earthquakes, those of intensity IV or V or less and which occur randomly, may be related to rebound, though there is no way to establish such a relationship.

Principal Earthquake Zones

47. The most direct way of categorizing the historic seismicity in this region is to define zones to represent areas susceptible to specific levels of earthquake events. Figure 8 shows boundaries for seismic zones near the project sites. They may be compared with Figure 4. Zone A follows the narrow band of intense seismicity along the St. Lawrence. The seismicity has been discontinuous along this trend; however, the historic record is relatively short. The intense seismicity may migrate through time along the zone. Thus, Zone A is shown with continuity along the St. Lawrence Valley. Its maximum observed intensity is X. Zone A is bounded by a narrow Zone B. Zone B is believed to be not prone to the maximum earthquake of Zone A. Maximum observed

intensity is only IV; however, Zone B represents, in principle, possible secondary faults that can be activated by the major faults in Zone A. Zone C is the hinterland area and includes the sites. In Zone C, the seismicity is of a low order as the level of historic events is no greater than II to IV. About 75 miles southeast of the sites the areal seismicity is greater with events to V to VI (see Figure 4). This area forms a large Zone D, not shown in Figure 8.

PART VI: EXAMINATION FOR ACTIVE FAULTS

48. Earlier sections of this report have established that mapped faults are ancient ones which date back to orogenies during early Paleozoic time and to subsequent disturbances during the Triassic. The predominating lithologies, metamorphosed shales and graywackes, do not show up those faults that are present because of the similar characteristics of the rocks on both sides of the fault planes. Thus, the faults are extremely difficult to recognize in the field, even where the fault plane is exposed. Figure 9 shows typical ground terrain where a mapped fault crosses a road. The rocks are very poorly exposed. Even along streams, the glacial detritus is so thick that bedrock can seldom be examined. The ground cover in the forests is composed of a thick ground litter of organic matter (see Figure 10) which obscures any details of the underlying soil or rock. It is impossible in these forests to walk a fault in order to follow its trace, even were the fault recognizable at some point. In actuality, fault separations are seen almost solely on certain of the mountain slopes, and then only where bedrock changes can be noted. For the most part, the faults have been determined by stratigraphic evidence, particularly through dating of fossil remains of graptolites in the shales. Missing portions of the stratigraphic column, or repeated sequences in the stratigraphic column, are explainable as displacements caused by faults. Thus the fault traces are determined inexactly without the fault contacts having been seen.

Association of Earthquakes with Tectonism and Faults

49. The association of earthquakes with faults is on the basis of the elastic rebound theory. Strains build up in rocks of the earth's crust due to tectonism. These strains may become greater than that which the rock can sustain. The rock fails by slipping along a fault, and the strain is relieved along the plane of the fault. Thus, the strained portions of the rock can experience a sudden rebound. The movement occurs elastically, and vibratory motions (the earthquake) are set up.

50. The tectonism which developed the faults in the general project area occurred early in geologic time. Considerable erosion has taken place since then, but there has been no tectonism during the intervening time and none is evident at present. Glacial rebound is occurring. Its contribution toward the activation of faults is believed to be minor; however, many of the small earthquakes, intensity IV or less, might be attributed to glacial rebound.

51. From the evidence provided by historic earthquakes, present-day tectonism appears to be geographically restricted to an irregular belt along the St. Lawrence River. This tectonism is poorly understood, but the major earthquakes along the St. Lawrence are presumed to be the result of fault movements along this zone of activity. The historic earthquakes have not caused fault movements that are seen on the ground surface. Such movement has occurred principally in the subsurface.

Definition of Active Faults

52. Faults are considered to be active if it is judged that they may move at some time in the near future. For engineering, it means that they have the potential for moving during the life of a structure. The principal criterion for making this prediction is whether they have moved in the recent past.

53. The Nuclear Regulatory Commission (formerly the Atomic Energy Commission)[15] uses the following criteria:

- a. Datable movement during the past 35,000 yr. (The limit of accurate radiocarbon dating.)
- b. Datable movement more than once in the past 500,000 yr. (Marine terraces.)
- c. Structural interrelation whereby a fault can be shown to move if movement occurs on a different fault with proven activity.
- d. Instrumentally determined macroseismic activity relatable to a fault.
- e. Projection of a proven active fault through or into areas where all evidence of the fault or its activity is obscured, as by thick alluvium.

The International Atomic Energy Agency[16] adds the following additional criteria:

a. Evidence of creep movement along a fault. Creep is slow displacement not necessarily accompanied by macroearthquakes.

b. Topographic evidence of surface rupture, surface warping, or offset of geomorphic features.

54. A practice that has come into use for engineering evaluations is to call a fault active if it disturbs any Holocene deposits. Holocene is that period which encompasses the last 10,000 yr. Displacement of surficial gravels, displacement of the most recent glacial deposits, and displacement of Holocene alluvium are accepted criteria.

55. All of the above criteria presume that there are surface manifestations of fault movements. However, faults may move in the subsurface and have no surface manifestations. A lack of surface evidence is common east of the Rocky Mountains in the United States and in Canada.

Mapped Faults

56. Traverses were made across mapped faults and lineations in order to examine the faults for evidences of movement. The traverses are shown in Figure 11. No evidence of movement was seen.

57. Local residents were questioned to learn if they knew of ground breakages anywhere in the area. No one knew of any such events.

Lineations

58. Lineations, or linears, are those linear features that are found in tonal changes in air imagery and in the alignment of rivers, terrace boundaries, etc. They may be the result of a multitude of causes. Thus, they may represent actual faults or they may be entirely unrelated to faults.

59. An Earth Resources Technology Satellite (ERTS) image of northwestern Maine and the St. Lawrence Valley is shown in Figures 12 and 13. Figure 12 shows the image without retouching; Figure 13 shows a

superposition of lines which mark out the linears. The two images may be compared in order to recognize the patterns which led to the selection of the linears.

60. An attempt was made to examine these linears on the ground in the same traverses that are shown in Figure 11.

61. These linears may very reasonably represent faults. They are fault zones that could have become manifest as a result of differentials in the considerable erosion which has occurred. The features may also have been modified to some extent by the last glacial advance. However, the linears, generally, are not believed to have been the result of glaciation alone.

62. No sign of surface activity of faults was seen during the examinations of these linears.

Noises

63. Local residents were asked if they could recollect having felt any earthquake motions. Some of them knew that an earthquake had been felt strongly in 1925. They also spoke of feeling earthquakes in other years, but their recollections were uncertain.

64. Some of the people who spent time hunting in the mountains said they had heard noises that sounded like thunder at a distance. However, the sky might be clear with no suggestion of atmospheric conditions that would be associated with thunder. These noises were heard mostly in the autumn approximately with the onset of cold weather, meaning the first frosts. The noises might be heard several times in a day with individual durations of about half a minute. The noises are heard only in the mountains, notably on Rocky Mountain. They are not heard in the lowlands. These noises are never accompanied by ground motions. A thunderlike noise is typical of earthquakes. Earthquake ground motions can be transmitted into the air as audible sounds. However, such transmissions do not happen without ground shaking. The absence of ground motion tends to rule out earthquakes as the cause of these noises.

65. There are rockslides in the mountains. It is possible that frosts, through frost heave, tend to precipitate slides that were incipient earlier. Such slides could account for the noises and would explain why the noises are restricted to the mountains. As the noises are said to be never accompanied by ground motions, it is not likely that they are associated with local earthquakes.

Activity of Faults

66. None of the faults or linears show any evidences of activity in the general area of the project.

PART VII: EARTHQUAKE INTENSITIES

Maximum Intensities

67. The largest observed earthquake intensities (MM) at the points of origin (I_o) for the zones in Figure 8 are as follows:

Zone A: I_o = X

Zone B: I_o = VI

Zone C: I_o = IV

Zone D: I_o = VI

68. The data have been examined by others, principally Howell[17] and Hadley and Devine.[10]

Howell

69. Howell contoured the intensity data into a map of cumulative seismic hazard for the years 1638 to 1971. His contours (see Figure 14) are spread according to the data and are not controlled by any geologic or tectonic boundaries. His contour numbers are equivalent to the MM scale of intensity. Thus, in Figure 14 he shows an intensity of IX for Zone A. At the damsites, Zone C, he has a value of about VIII. He has generalized these contour patterns into a map which shows Average Regional Seismic Hazard Index (Figure 15). The value for a broad band along the St. Lawrence Valley is IX. At the damsites it is VII.

Hadley and Devine

70. Hadley and Devine developed their seismotectonic map in three sheets. The first sheet carried mapped faults and other tectonic elements such as folds, uplifts, arches, shield boundaries, etc. The second sheet listed earthquake events by intensity. Their final sheet (see Figure 16 for northeastern United States) attempted to relate structural control to frequency of occurrence of earthquakes and to intensity. The damsites are in an area with the lowest category for the frequency of occurrence of earthquakes. Though high intensities might be felt at the damsites, the implications are that they would be generated in adjacent areas with greater potentialities for earthquakes. The St. Lawrence Valley is shown as a narrow zone with a high frequency

of earthquake occurrence and an intensity level of IX.

Intensity Patterns

71. Isoseismal maps, containing intensity patterns for three earthquakes originating in the St. Lawrence Valley, are shown in Figures 17-19. Of these, the most severe is that of 1 March 1925. The intensity at the epicenter was VIII or IX, depending on interpretation. In the vicinity of the damsites, the intensity was VI.

72. For all three of the earthquakes, there is a distinct elongation of the isoseismal contours in a northeast to southwest direction. Correspondingly, there is a shortening of the contour interval to the southeast toward the damsites, implying a significant increase in the rate of attenuation.

Attenuation from the St. Lawrence to the Damsites

73. A comparison was made between isoseismals from the St. Lawrence toward the damsites with those of the 1971 San Fernando earthquake in California. The comparison is shown in Table 3. It may be noted that the St. Lawrence earthquake of 1925 was somewhat larger than the San Fernando earthquake of 1971. The distances to the boundaries of

Table 3

Comparison of Attenuation of St. Lawrence and San Fernando Earthquakes

Attenuation to the Southeast

	Distance (km) to Outer Boundary of MM Intensity Level					
	IX	VIII	VII	VI	V	Magnitude
St. Lawrence Earthquake: 1 March 1925	16	26	47	120	182	7.0
San Fernando, California, Earthquake: 9 February 1971	15	26	44	75	130	6.5

comparable intensity levels are slightly higher for the St. Lawrence. Essentially, the comparison suggests that attenuation from the St. Lawrence Valley toward the southeast is the same as the attenuation in California. Correspondingly, data on California earthquakes expressed in distance from the source may be used for the damsites in northern Maine.

Relation of Intensity to Magnitude

74. The relation between intensity, magnitude, and felt area of earthquakes in northern New England and adjacent parts of Canada is shown in Figure 20.

75. The modified Gutenberg and Richter formula for relating intensity to magnitude (see Krinitzsky and Chang[18]) is applicable. The formula is:

$$M = 2.1 + 1/2\ I_o$$

The formula provides a best fit, or median, for the data.

Relation of Intensity to Magnitude and Distance

76. Milne and Davenport[19] analyzed five earthquakes from eastern Canada and provided intensity versus distance graphs for them. Their plot is shown in Figure 21. The earthquakes ranged in magnitude from 5.8 to 7.2. A more general graph that related intensity to magnitude and distance for eastern Canada is shown in Figure 22.

Maximum Credible Intensities

77. The maximum observed intensities for the zones in Figure 8 have already been stated. They are tabulated with corresponding magnitudes in Table 4.

78. The observed values cannot be regarded as the worst that can

Table 4

Intensities and Magnitudes for Seismic Zones in Northern Maine and Adjacent Canada

	Maximum Intensity (MM) I_o Observed	Corresponding Magnitude	Maximum Credible Intensity I_o	Corresponding Magnitude
Zone A	X	7.0	XI	7.5
Zone B	VI	5.0	VIII	6.0
Zone C	II-IV	4.0	VII	5.5
Zone D	VI	5.0	VIII	6.0

be reasonably expected to occur. A conservative approach requires that a provision be made for larger events.

79. A consideration at this point is the maximum length of fault that might be involved in an earthquake. Zone A along the St. Lawrence Valley has a length that is measurable in many hundreds of miles. The distance from Montreal out to the Gulf of St. Lawrence is over 400 miles. Assuming that Zone A contains a major fault along this length of which a portion, one-half or one-quarter of the length, may move at one time, one can consider what size of earthquake can be generated by this movement. Bonilla and Buchanan[20] (see Figure 23) have used worldwide data to show a relation between length of surface rupture of a main fault versus earthquake magnitude. A rupture of 100 miles or 160 km may very easily be accompanied by an earthquake with a magnitude of 7.5 to 8.5 and a corresponding intensity of XI. Thus, Table 3 has been expanded in Table 4 to include a magnitude 7.5 and an intensity of XI for Zone A. These are maximum credible events, or the largest that can reasonably be expected to occur. Zone B is taken as lower, at magnitude 6.0 and intensity VIII. Zone C is magnitude 5.5 and intensity VII. Zone D is magnitude 6.0 and intensity VIII, the same as Zone B. These are maximum events that can be generated in the respective zones. Larger values are possible in portions of Zones B and C through attenuation from Zone A.

PART VIII: SELECTED EARTHQUAKE GROUND MOTIONS FOR THE DAMSITES

Intensities at the Damsites

80. The intensities of the earthquakes in Zones A, B, C, and D at their origins (I_o) must be attenuated to provide intensities at the damsites (I_s). Table 5 shows intensities at the origins, distances of attenuation, and attenuated intensities. Also indicated is the field condition (near or far) at the damsites.

Table 5

Maximum Intensities at the Damsites

	Maximum Credible Intensity (I_o)	Distance to Dams, miles	Maximum Intensity at Dams (I_s)	Field
Zone A	XI	45	IX	Far
Zone B	VIII	40	VI	Far
Zone C	VII	10	VI	Far
Zone D	VIII	75	V-VI	Far

81. The attenuations were made with the use of the chart in Figure 22 made for eastern Canada by Milne and Davenport. The intensity VII for Zone C was taken at 10 miles distant and reduced to VI on the probability that it is not likely that an earthquake would occur closer to the damsite. The intensity XI from Zone A has been reduced to IX at the sites. The latter is the dominant motion at the dams. The faults show no activity at the surface. Thus, foci for maximum local earthquakes may be taken at depths of tens of miles below the surface and epicenters may be laterally several miles from the dams. There will be no surface breakage along faults. The local conditions are those for far-field effects, as well as a low likelihood of a maximum event. However, microearthquakes, measurable by instruments only, may be expected to occur nearer to the surface, possibly within a mile of the surface, possibly

deeper. These events are not of engineering significance.

Near Field Versus Far Field

82. In the near field of an earthquake, complicated refraction and reflection of waves cause a large range in the scale of ground motions. Some motions may be intense and there are high-frequency components in such motions. In the far field the waves are more orderly; they are more muted; and the frequencies are lower.

83. Limits to the near field for data from the West Coast of the United States were assigned by Krinitzsky and Chang.[18] These limits are believed to be directly applicable to the Dickey-Lincoln study area. They are shown in Table 6.

Table 6

Limits of the Near Field of Earthquakes in the Western United States (from Krinitzsky and Chang[18])

Magnitude	Maximum Epicentral Intensity, I_o	Radius of Near Field, km
5.0	VI	5
5.5	VII	15
6.0	VIII	25
6.5	IX	35
7.0	X	40
7.5	XI	45

Intensities Versus Peak Ground Motions

84. Figures 24, 25, and 26 show the dispersion of peak accelerations, velocities, and displacements, respectively, for a group of 187 earthquake records from the western United States. In each figure, the values were plotted for appropriate intensities, and the near field and

Table 7

Peak Horizontal* Bedrock Ground Motions and Durations for Earthquakes at the Damsites

Source of Earthquake	Maximum Intensity at Dams (I_s)	Field	Acceleration cm/sec^2	Velocity cm/sec	Displacement cm	Duration sec
Zone A	IX	Far	350	65	22	18
Zone B	VI	Far	180	30	18	11
Zone C	VI	Far	180	30	18	11
Zone D	V-VI	Far	150	23	16	10

Note: An acceleration of 1 $g = 980\ cm/sec^2$.

* Vertical components of motion may be taken as 2/3 the horizontal.

the far field have been separated. These data are from Krinitzsky and Chang.[18] For accelerations, there is a large difference between near and far fields. The differences are much less for velocities and displacements.

85. Reference to the full dispersion of data allows one to use the upper limits, or to use lower levels, consistent with the safety requirements of a structure. For dams with urbanized areas downstream, as in the case of the Dickey-Lincoln School sites, the upper boundary should be used.

86. For intensity versus duration of shaking (the full period of time in which accelerations were greater than 0.05 g), again data from the western United States were used. These are plotted in Figure 27 from work done by Chang.[21] The data in Figure 27 are for the far field.

87. No data are available for an intensity IX in the far field. However, projected values for intensity IX are shown in Figures 24 to 26 and are used in this report.

88. Peak ground motions and durations of shaking for bedrock were obtained as shown in Table 7.

Comparison with Alternative Methods

89. Comparisons can be made at this point with other methods that are commonly used.

Intensity-acceleration correlations

90. Commonly used correlations between intensity and acceleration are shown in Figure 28. Included are correlations established by Neumann,[22] Gutenberg and Richter,[23] Hershberger,[24] Medvedev, Sponheuer, and Kárnik (see Barosh[25]), and Trifunac and Brady.[26] All of these are either mean or average values made with various levels of data accumulation. They do not provide for the spread in data and they do not distinguish between near-field and far-field conditions. From Figure 28, the Hershberger line gives a peak acceleration of about 1000 cm/sec^2 for an intensity at the site of IX. The Gutenberg and Richter line gives 400 cm/sec^2. In this study, an acceleration of 350 cm/sec^2 is arrived

at because of the far-field conditions at the site. For intensity VI, the Trifunac and Brady mean line gives 75 cm/sec^2. (Other data by Trifunac and Brady are discussed separately in following sections of this report.) The Hershberger and the other lines give less. The value accepted for this study is 180 cm/sec^2.

91. The values in this report are believed to be more realistic than those which are obtained from the correlations cited above.

Nuttli's studies
for central United States

92. Professor O. W. Nuttli[27] developed the appropriate ground motions for a far-field condition for the worst earthquake that might occur in the New Madrid region of southeast Missouri. A maximum earthquake in the New Madrid area is comparable to a maximum earthquake in Zone A of the St. Lawrence Valley. The attenuations in the central United States are believed to be less than those in a southeast direction away from the St. Lawrence Valley. Thus, Nuttli's values should be relatively conservative.

93. Table 3 of Nuttli's 1973 report[27] was used. An interpolation was made for a distance of 45 miles from Zone A in the St. Lawrence to the site. The wave frequency was taken at 0.3 Hz as this gave the severest motions. Nuttli's values are:

Distance: 45 miles
Acceleration: 0.12 g
Velocity: 58 cm/sec
Displacement: 27 cm

94. Nuttli's values are not peak values. They are peak recurrent values and they are the resultant motions rather than the horizontal motions. However, the resultant motions are believed to be directly comparable to the horizontal motions. Nuttli's velocities should be comparable to peak velocities in this report, but his accelerations would be expected to be lower. His velocity of 58 cm/sec compares favorably with a velocity at the Dickey-Lincoln School sites of 65 cm/sec. Nuttli's displacement of 27 cm is high compared with 22 cm. His acceleration of 0.12 g versus 0.35 g is low, as was anticipated. Based

on the comparison of velocities, the motions at the Dickey-Lincoln School sites are comparable to motions that Nuttli would assign. The peak acceleration used in this study is more conservative than the acceleration of Nuttli.

Schnabel and Seed

95. Schnabel and Seed[28] provided values for maximum accelerations in rock for the western United States. Their curves are shown in Figure 29. For a maximum event at a distance of 45 miles, the highest acceleration from recorded observations is about 0.17 g. If an acceleration is taken from the "probable upper bound," it is about 0.25 g. The latter is less than the 0.35 g taken for the Dickey-Lincoln School sites.

U. S. Geological Survey: western United States

96. U. S. Geological Survey data for selected earthquakes of the western United States are shown in Figures 30 to 32. These relate accelerations, particle velocities, and displacements, respectively, to magnitude of earthquake and distance from source. These data were developed by Page et al.,[29] for studies related to the Trans-Alaska Pipeline. Superimposed are lines taken from Nuttli[27] which represent a maximum New Madrid earthquake for the central United States with a magnitude of 7.5.

97. Accelerations from Figure 30 show that at a distance of 72 km (45 miles) for a maximum earthquake in which M equals 7.0 to 7.9, higher values will be obtained than those cited by Nuttli. The value obtained from the USGS chart is between 0.18 and 0.20 g. Thus, the 0.35 g selected for the Dickey-Lincoln School damsites is conservative compared to the USGS data.

98. Velocities from Figure 31 for a maximum event at 72 km provide a value of about 25 cm/sec. This is much lower than 65 cm/sec obtained for the Dickey-Lincoln School damsites and is also lower than the values that Nuttli proposes. The velocity values for the Dickey-Lincoln School sites are more conservative than that which is indicated by USGS data.

99. USGS displacements (see Figure 32) also are lower than those

for the Dickey-Lincoln School sites. The USGS would obtain about 10 cm. Nuttli's value is 27 cm. The value of 22 cm for Dickey-Lincoln School falls between these.

U. S. Geological
Survey: eastern United States

100. For the eastern United States, the U. S. Geological Survey[30] uses the distance versus acceleration graph shown in Figure 33. The curves (solid lines) are taken from Schnabel and Seed[28] and were modified (dashed lines) by attenuating the lines according to the attenuations of Nuttli[27] for the central United States. At a distance of 72 km, there is very little change from Schnable and Seed for a magnitude 7.5 event, the acceleration being about 0.18 g.

Trifunac and Brady

101. The values generated by Trifunac and Brady[26] for ground motions in relation to intensity for the western United States are shown in Figure 34. The values do not distinguish between near field and far field as was done in this report. Otherwise, the data used by Trifunac and Brady and in this report are the same.

102. The values of Trifunac and Brady for one standard deviation on the plus side for an intensity IX are interpolated as:

Acceleration: 0.60 g

Velocity: 60 cm/sec

Displacement: 20 cm

103. The acceleration is double that of this report. The other values are comparable to those in this report though slightly lower.

Ambraseys

104. Ambraseys (see Johnson and Heller[31]) has reasoned that there is no upper bound to ground acceleration but that particle velocity has an upper bound. Ambraseys developed an empirical equation for the relationship between the peak particle velocity, the magnitude of an earthquake, and the distance from the focus which was developed for epicentral distances of 10 to 150 km and magnitudes 5 to 7. Figure 35 shows maximum values for the above relationships. At a distance of 72 km, Ambraseys obtains a maximum velocity of 30 cm/sec for a magnitude

7 earthquake. No magnitude 7.5 event is shown; however, an extrapolation to that level would obtain a velocity of about 68 cm/sec. Thus, the 65 cm/sec for the Dickey-Lincoln School sites closely resembles what might be projected using the Ambraseys analysis.

Milne and Davenport

105. Milne and Davenport[19] developed a contour map for eastern Canada which shows accelerations as a percent of g with a return period of 100 yr. Their map is shown in Figure 36. The Dickey-Lincoln damsites are located adjacent to the Milne and Davenport 0.10-g contour. The value of 0.35 g assigned in this report is much more conservative.

Summary

106. Table 8 provides a comparison between the values used in this report for an intensity IX earthquake at the damsites and values taken from the authors discussed above.

107. For data from the western United States used by Krinitzsky and Chang[18] and Trifunac and Brady,[26] the maximum observed far-field acceleration is about 0.25 g at intensity VII; the maximum observed far-field velocity is about 35 cm/sec at intensity VII; and the maximum observed far-field displacement is about 18 cm at intensity VI. Far-field motions greater than these are interpreted.

108. The work done in this study was reviewed by Dr. David B. Slemmons, geological consultant, and Dr. Otto W. Nuttli, seismological consultant. They concurred with the values adopted in this report. Their comments are contained in Appendix A.

Time Histories of Ground Motion

109. Dr. Nuttli was asked to select four accelerograms for scaling to provide the time histories of ground motion in bedrock at the damsites. Three records were requested for a Zone A earthquake and one for a Zone C earthquake. Zone B will be scaled, with appropriate peak motions, using the same earthquakes as used for Zone A. Similarly, Zone D will use the same earthquake as Zone C. The scaled records will provide design earthquakes at bedrock for analyses of the foundation soils and structure.

Table 8

Comparison of Peak Horizontal Ground Motions (Interpreted from Various Authors) for Bedrock at Dickey-Lincoln School Damsites

Authors	Acceleration g	Velocity cm/sec	Displacement cm
Krinitzsky and Patrick	0.35	65	22
Nuttli[27]	0.12	58	27
Schnabel and Seed[28]	0.17*	--	--
	0.25**	--	--
USGS: western United States	0.20	25	10
eastern United States[2]	0.18	--	--
Trifunac and Brady†[26]	0.60	60	20
Ambraseys[31]	--	68††	--
Milne and Davenport[19]	0.10‡	--	--

* Recorded value.
** Interpreted upper boundary.
† Mean plus one standard deviation.
†† Interpolated by Krinitzsky and Patrick.
‡ Recurrent per 100 year.

110. Nuttli's selected events are contained in his letter in Appendix A.

111. The records Nuttli selected for Zone A and Zone B earthquakes, to be scaled for the damsites, are (a) the San Fernando, California, earthquake of 9 February 1971 using the Wrightwood, California, record; (b) the El Centro, California, earthquake of 8 April 1968 using the record at the El Centro Imperial Valley Irrigation District station; and (c) the Northern Utah earthquake of 30 August 1962 using the Logan, Utah, record. For Zone C and Zone D, Nuttli recommends the record for the Hollister, California, earthquake of 8 April 1961 using the record at Hollister, California.

Induced Seismicity at the Reservoirs

112. Earthquakes are known to have occurred coincident with filling and with changes of water levels in reservoirs. The occurrences are few, less than three dozen out of the thousands of reservoirs that exist worldwide. At only one site (Koyna in India) was an induced earthquake severe enough to damage the dam. Earthquakes strong enough to be related to damage (intensity VII or greater) have been induced at only five reservoirs in the world. All of these reservoirs are large: volumes of water in billions of cubic metres; heights of dams greater than 100 metres.

113. The energy released in any significant earthquake is much greater than the energy that can be related to load in a reservoir. The earthquake is the result of tectonism, the buildup and sudden release of stresses in the earth's crust. Loading from a reservoir is no more than a triggering action. The reservoir may touch off an earthquake that is about to happen for other reasons, but the reservoir does not cause the earthquake. Hence, the maximum credible earthquakes for which the dams are designed include any earthquake that might be induced.

PART IX: SUMMARY AND CONCLUSIONS

114. Mapped faults and interpreted lineaments were examined in air imagery and in overflights. A ground reconnaissance was made of these features. No evidence of active faults was seen in the general area of the damsites. It is believed that the faults which are present are ancient ones and are inactive. Active faults are believed to be restricted to a narrow band along the St. Lawrence River. There the faults are obscured by alluvial drowning. The seismic history shows that major earthquakes occur in the St. Lawrence Valley but that the level of seismicity in the area of the damsites is low. Four zones were assigned. Zone A is a band in the St. Lawrence Valley in which the most severe earthquakes can occur. Its distance from the damsites is 45 miles. Zone B borders Zone A and has a lower level of potential earthquakes. Zone B is 40 miles from the damsites. The remaining area, which includes the damsites, is Zone C and has the lowest seismic risk. A Zone D is interpreted 75 miles to the southeast of the damsites. Zone D has a slightly higher level of seismic risk than Zone C. The most severe bedrock ground motion at the damsites will come from an earthquake in Zone A. The motion at the damsites after attenuation over a distance of 45 miles is interpreted to have a peak acceleration of 0.35 g, a peak velocity of 65 cm/sec, and a peak displacement of 22 cm. The duration is estimated at 18 sec. Possible reservoir-induced seismicity is allowed for in the postulated earthquakes. A selection of accelerographs is recommended for scaling in order to provide time histories of bedrock ground motions for dynamic analysis.

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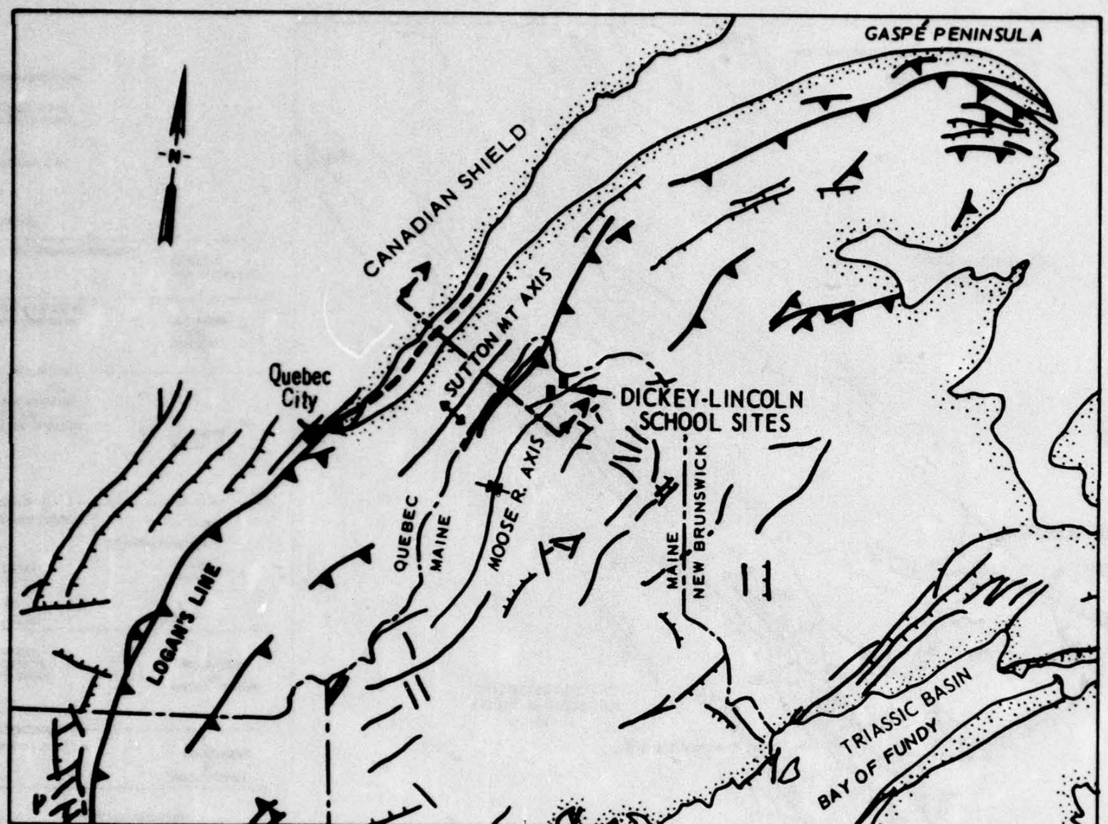


Figure 1. General tectonics, northern Maine and adjacent Canada (from USGS Tectonic Map of North America compiled by Philip B. King, 1969[1])

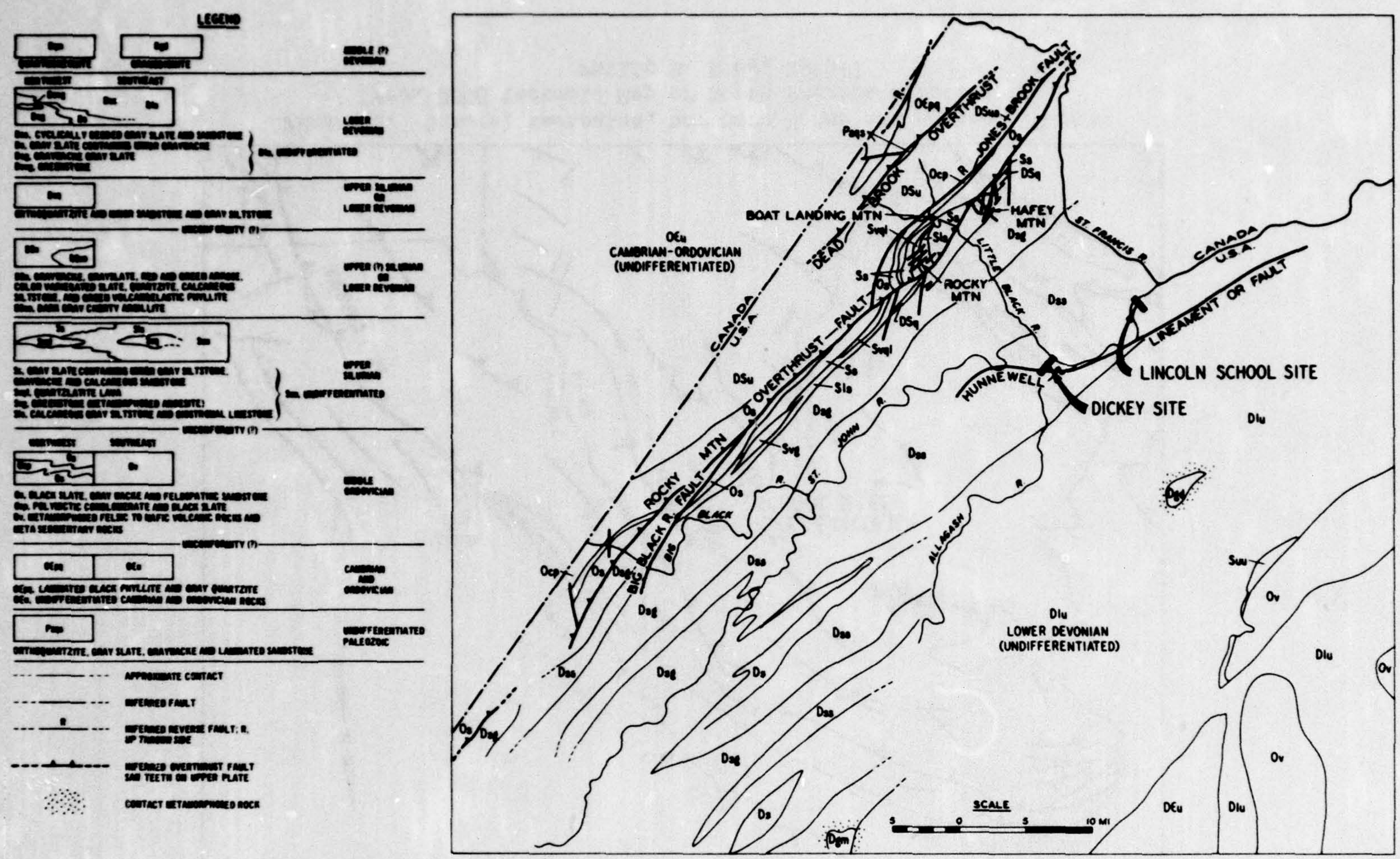


Figure 2. General geology of northwestern Maine (after Boudette et al.[2])

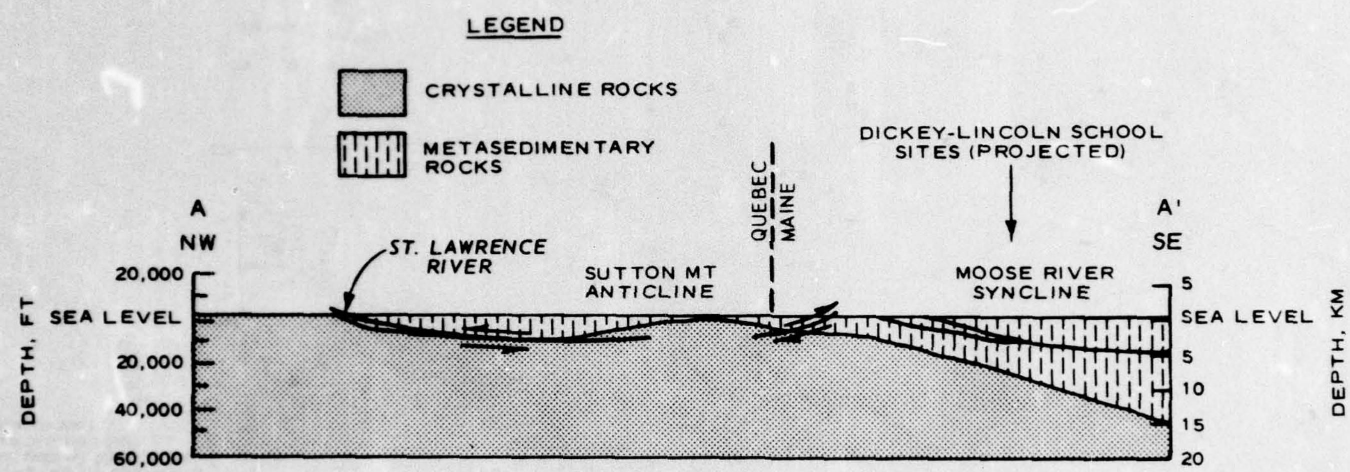


Figure 3. Schematic section from the Canadian Shield to northwestern Maine (after Cady[3])

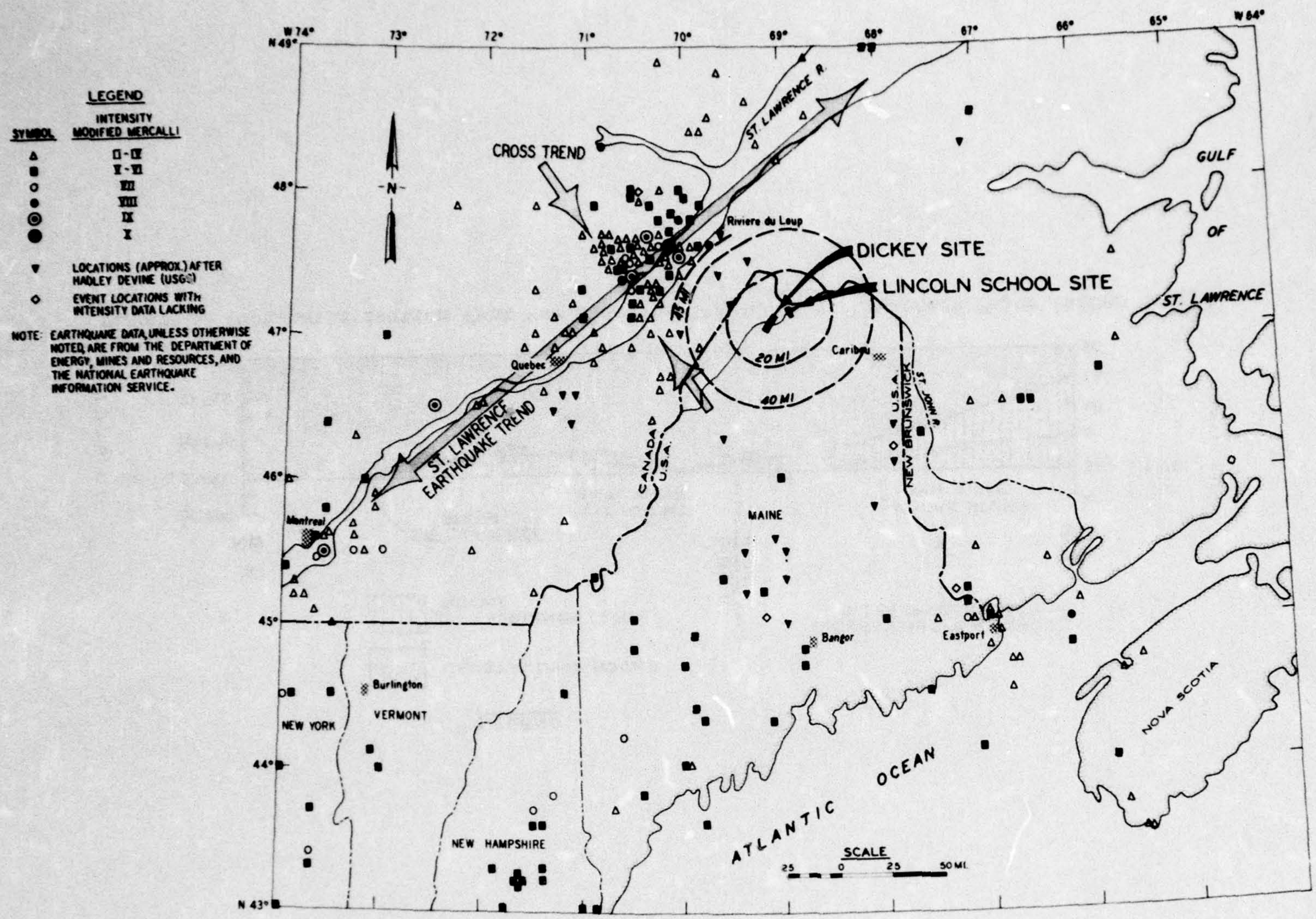


Figure 4. Historic earthquakes in northern New England and adjacent parts of Canada: 1638 to 1975

MODIFIED MERCALLI INTENSITY SCALE OF 1931

(Abridged)

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbed persons driving motor cars.

IX. Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Figure 5. Modified Mercalli intensity scale of 1931 (abridged)

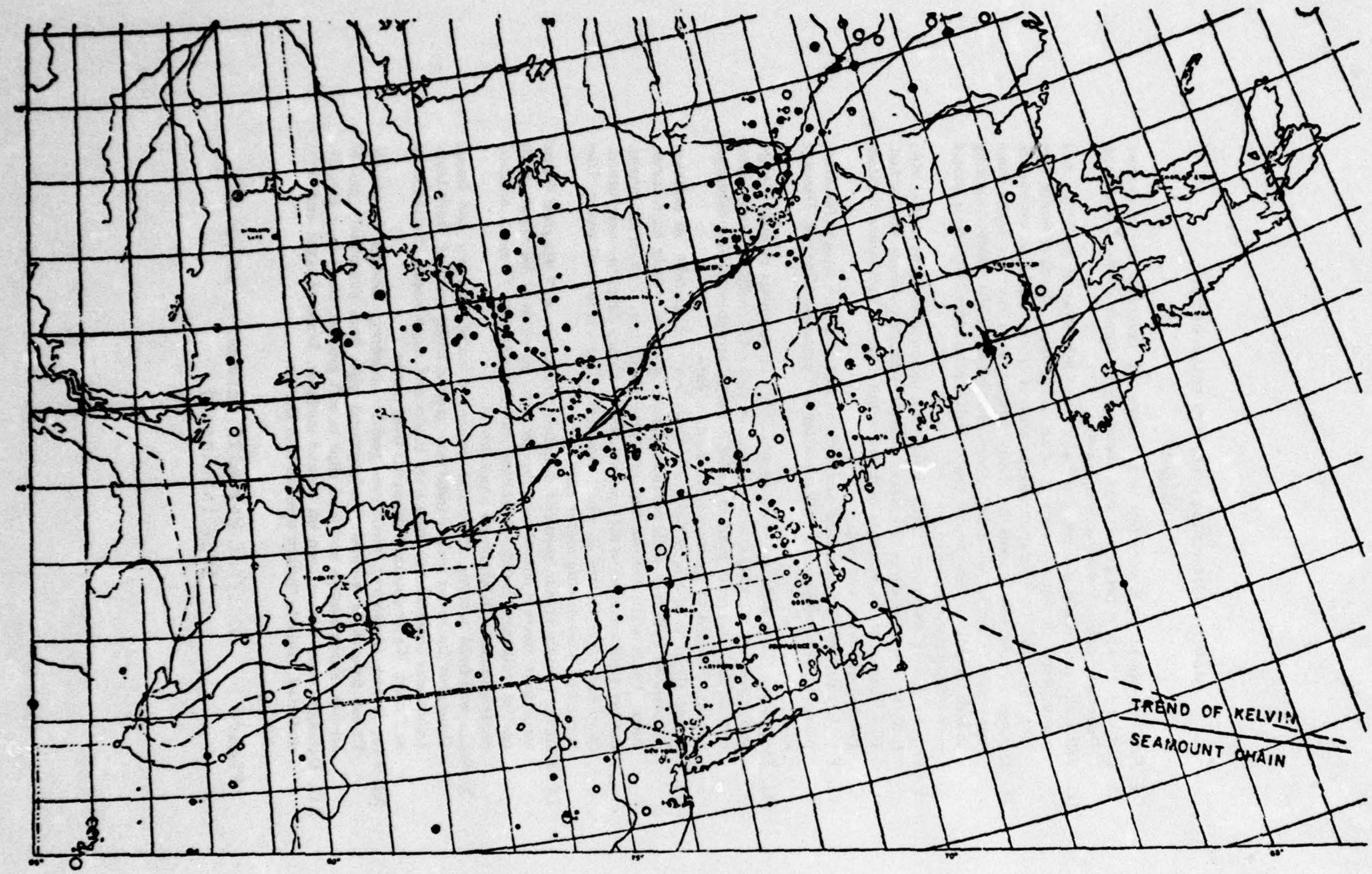


Figure 6. Seismicity in northeastern North America (1928 to 1959) with a NW-SE trend through Boston (after Smith[7])

Figure 7. Alluvial drowning along the south shore of the St. Lawrence River midway between Quebec City and Rivière du Loup

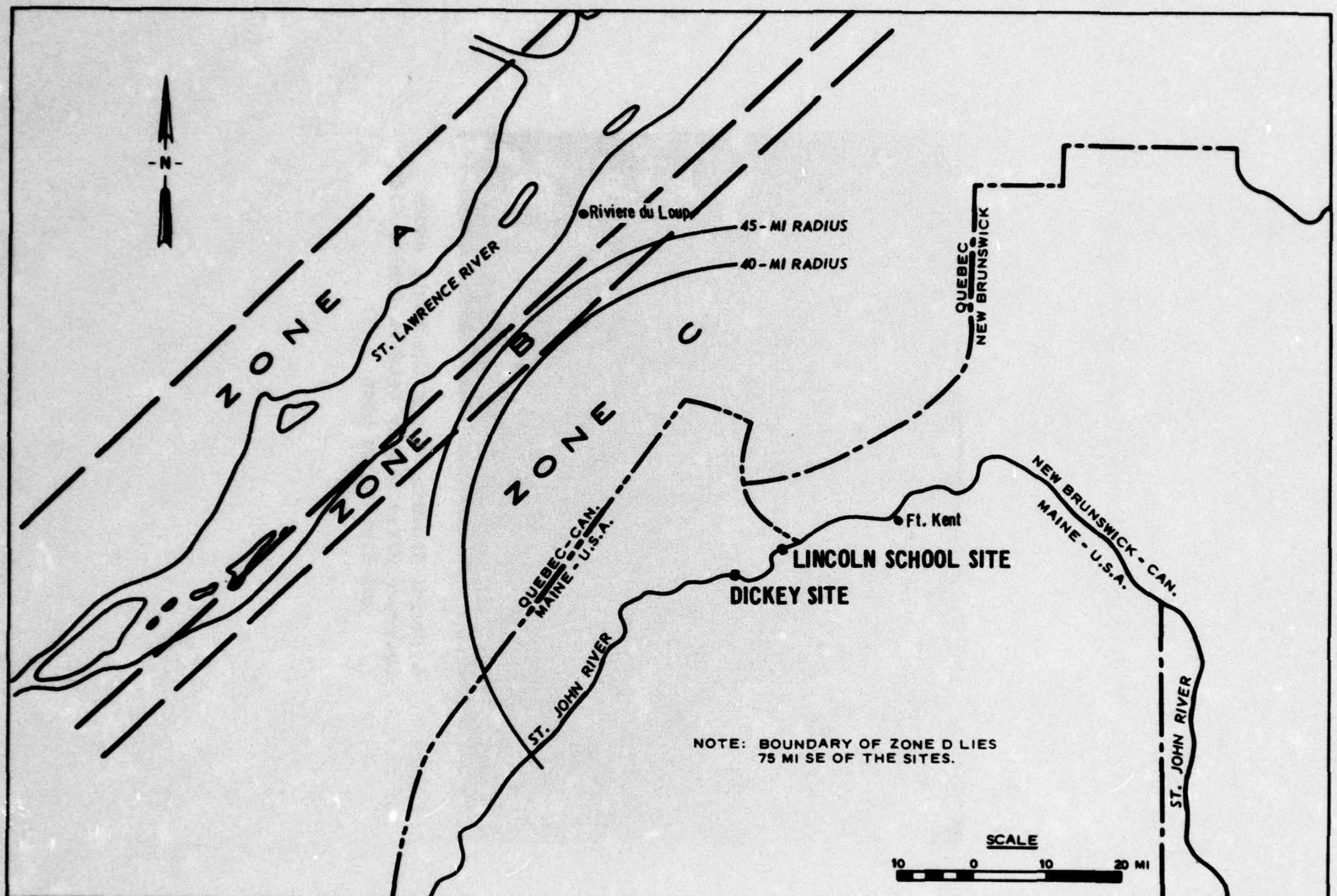


Figure 8. Seismic zones in the general area of the project

Figure 9. Typical ground terrain where a fault crosses a road in the project area

Figure 10. Example of organic ground litter in the project area

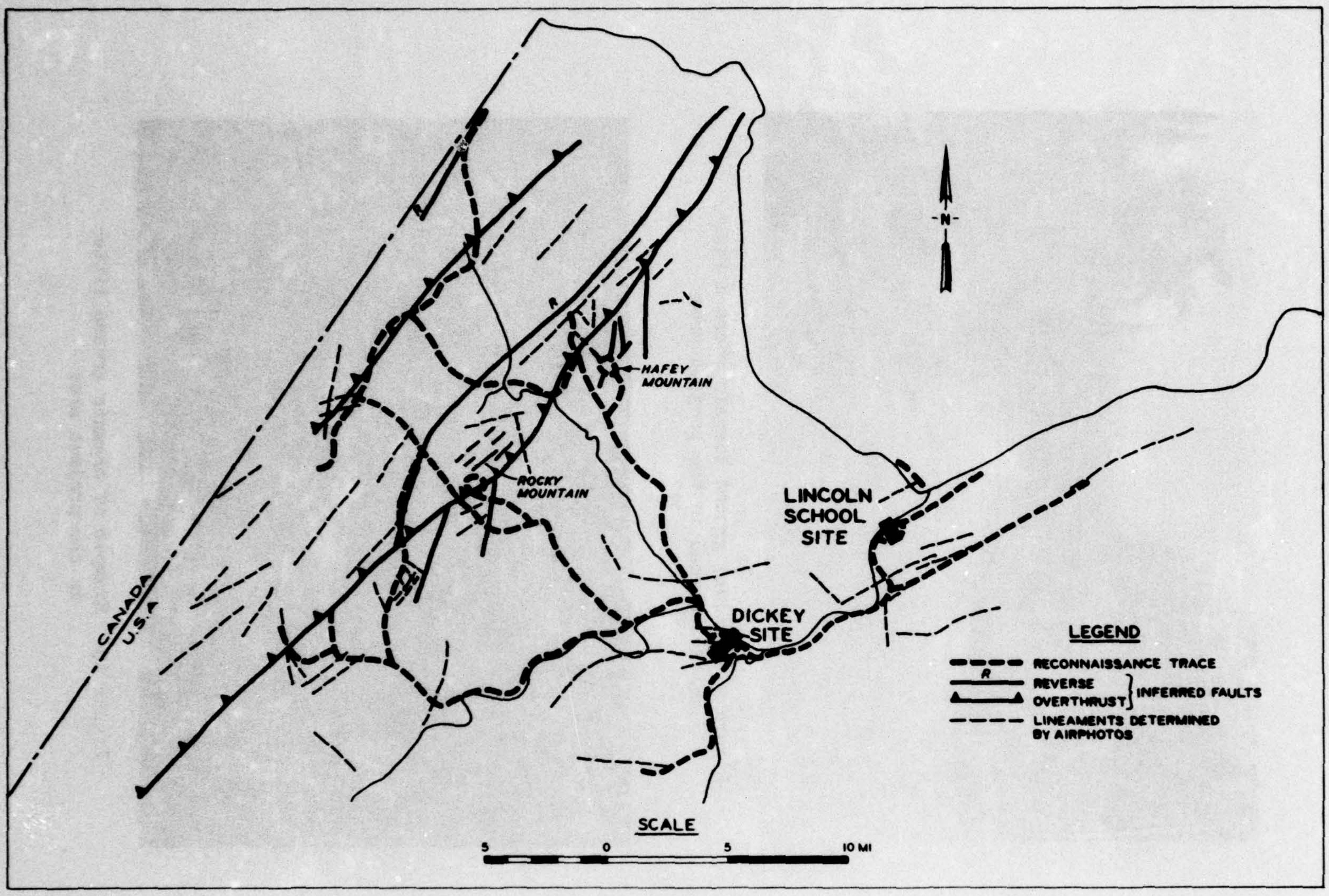


Figure 11. Ground traverses across faults and lineations in the project area

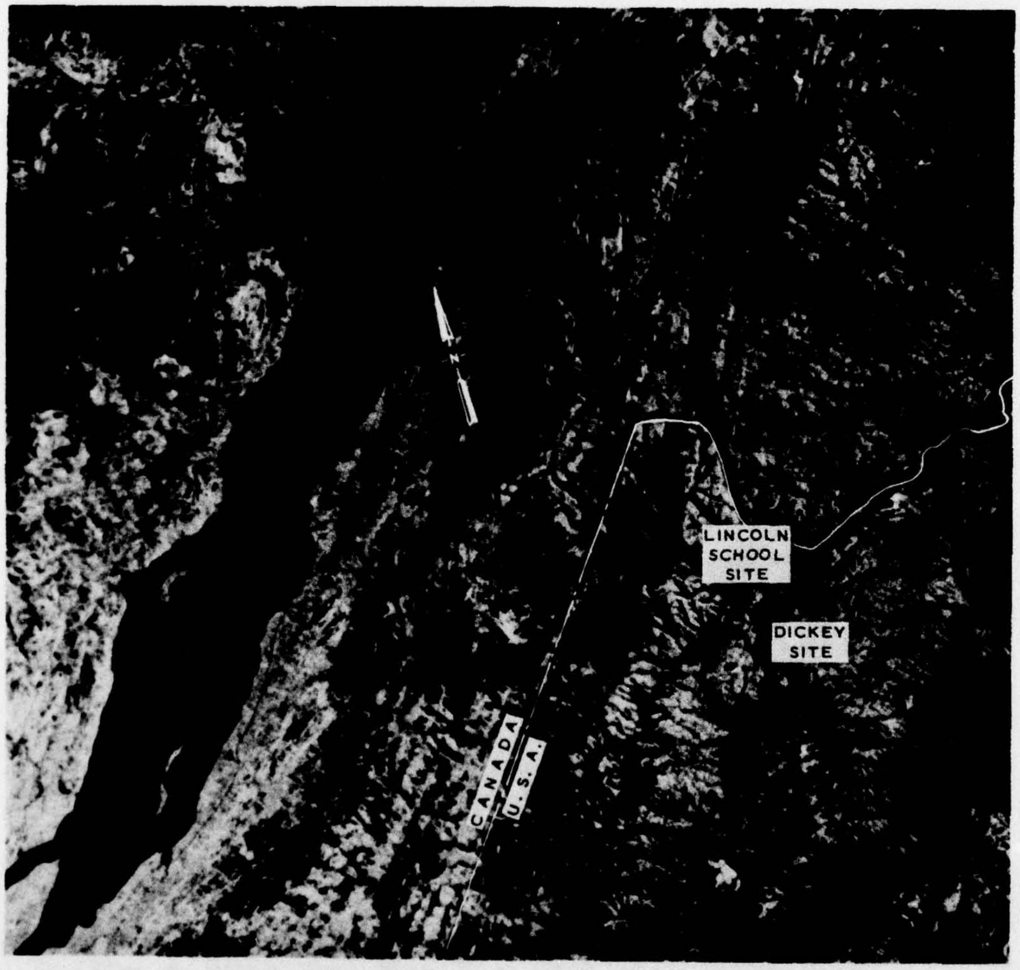


Figure 12. Earth Resources Technology Satellite (ERTS) image of northwestern Maine and the St. Lawrence Valley

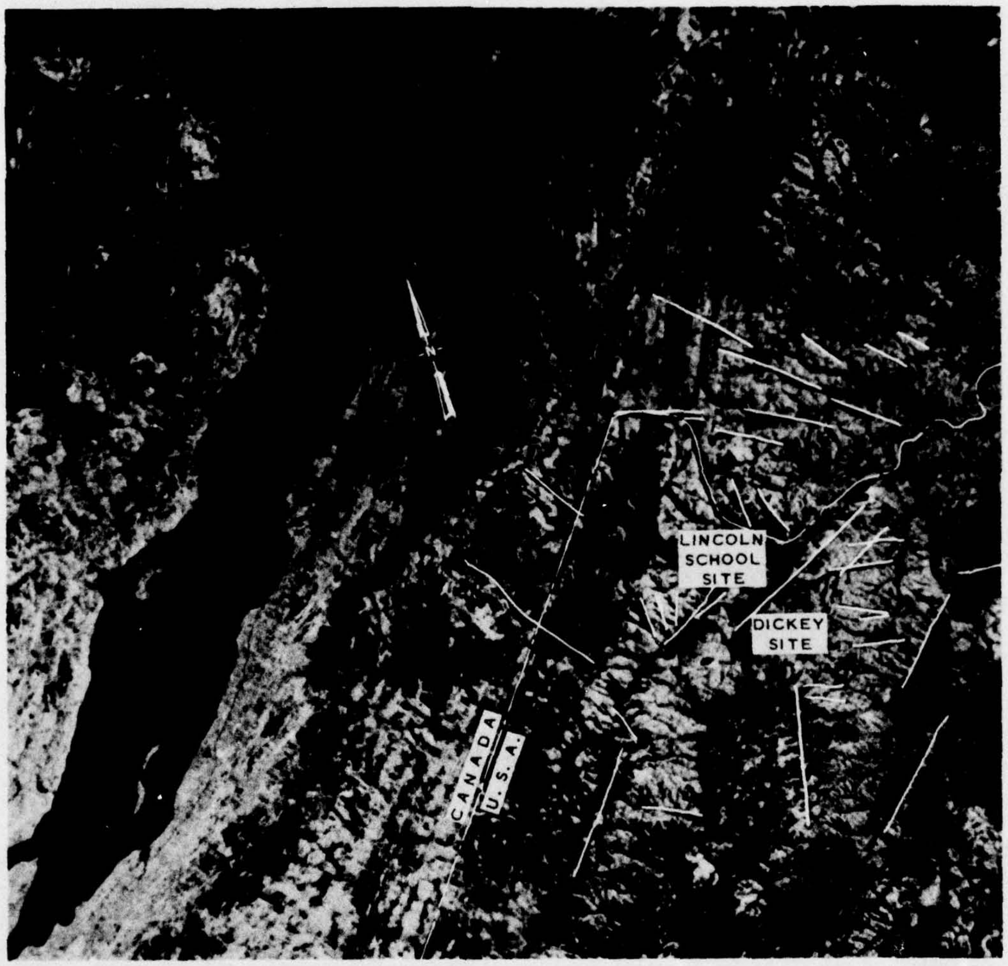


Figure 13. Selected linears superimposed on the image in Figure 12

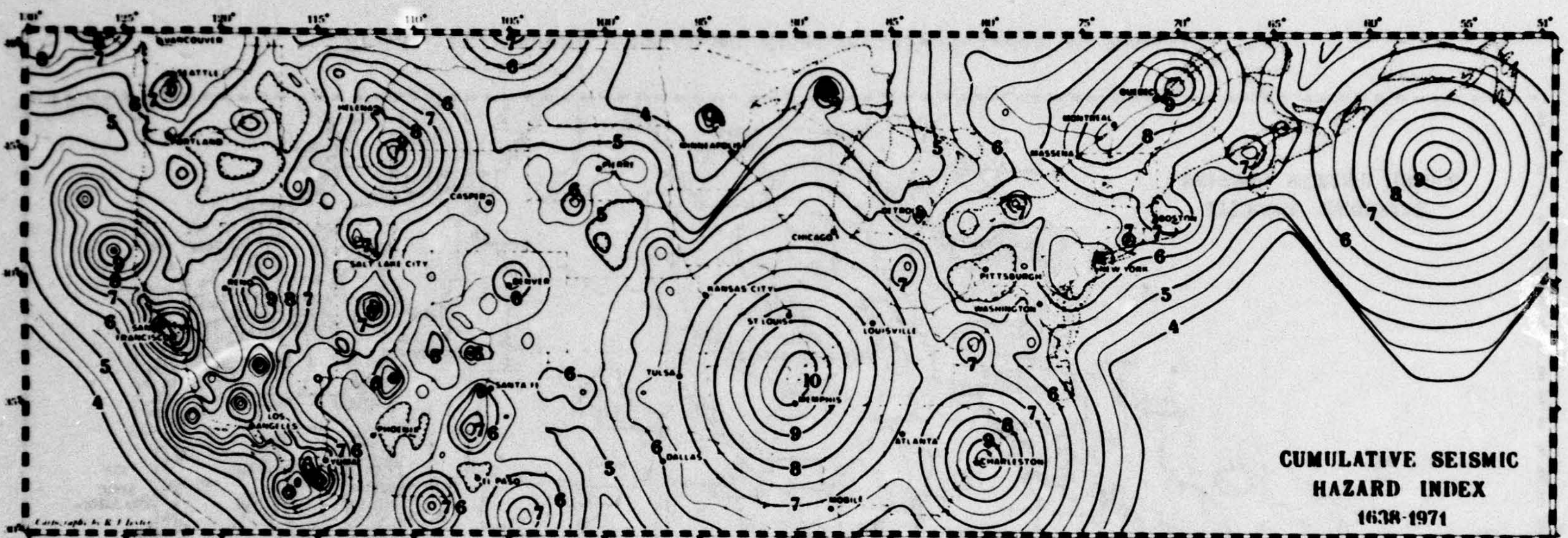


Figure 14. Cumulative Seismic Hazard Index (1638-1971) by Howell[17]

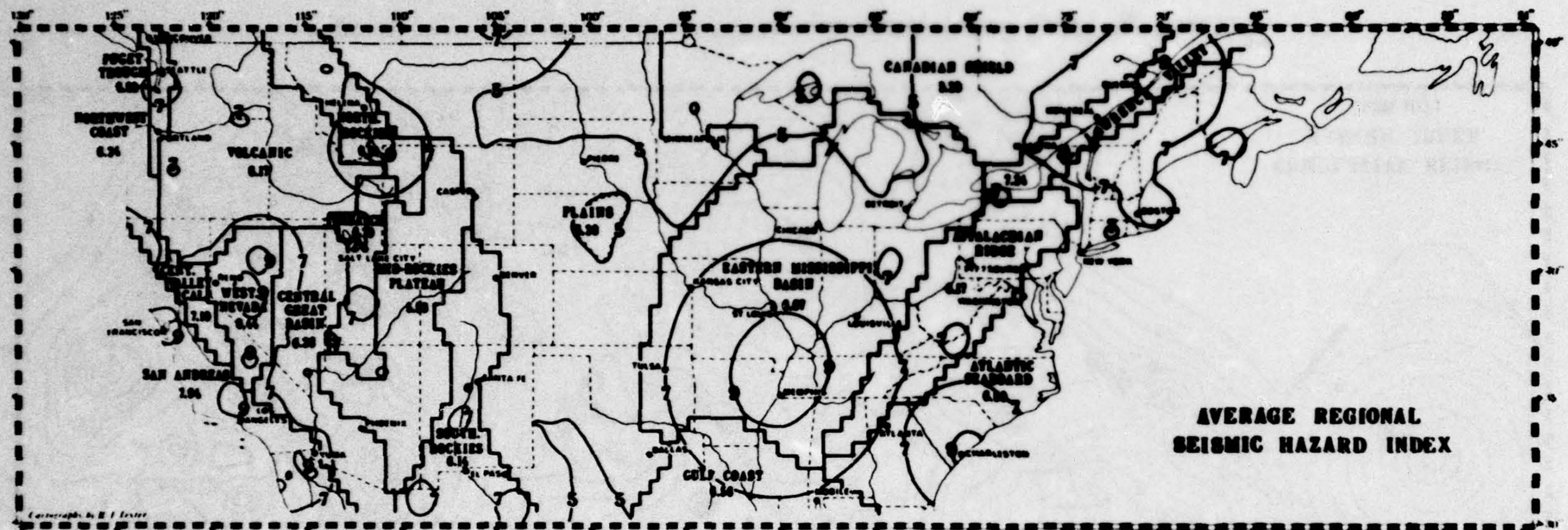


Figure 15. Average Regional Seismic Hazard Index by Howell[17]

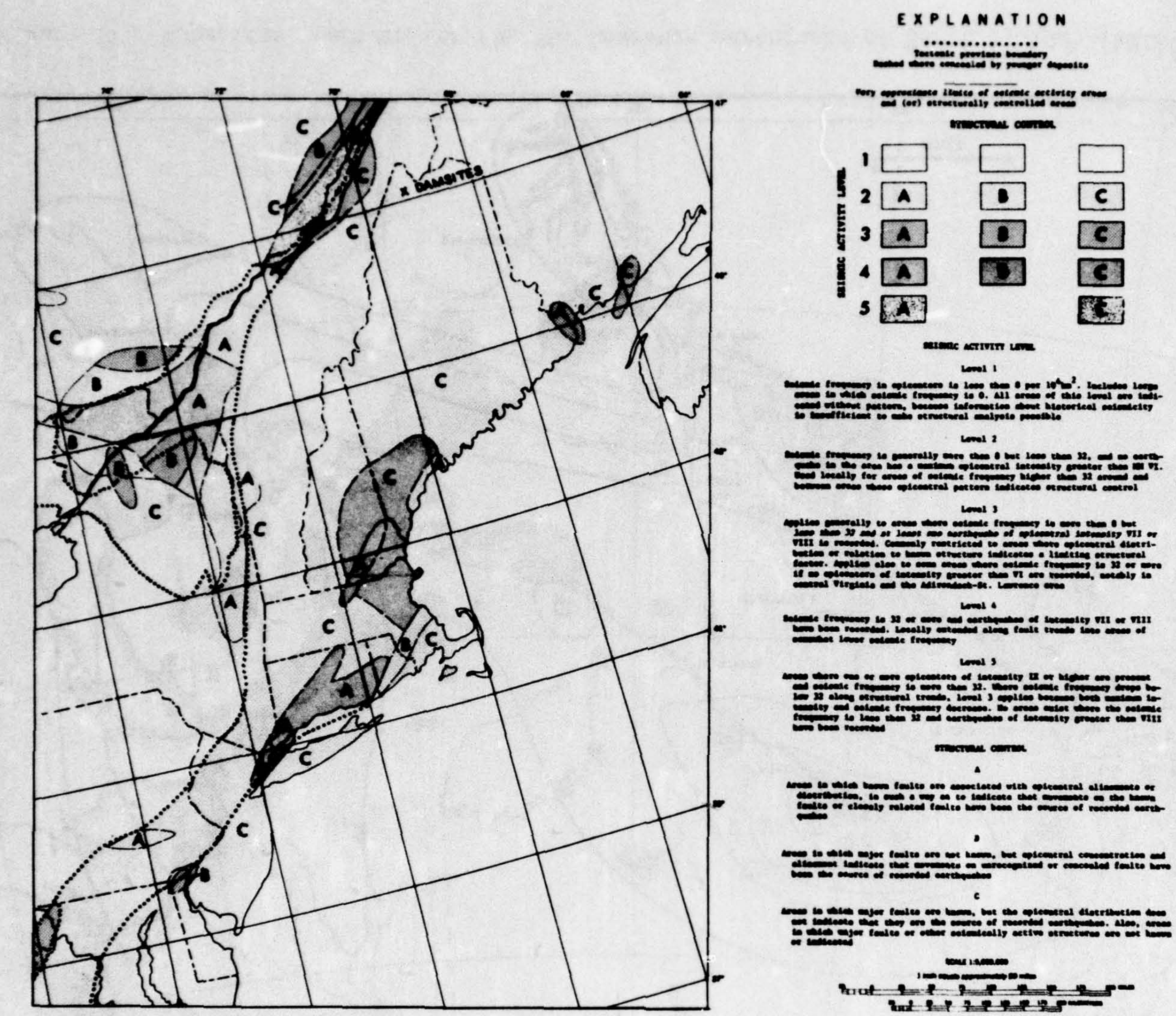


Figure 16. Seismic activity levels by Hadley and Devine[10]

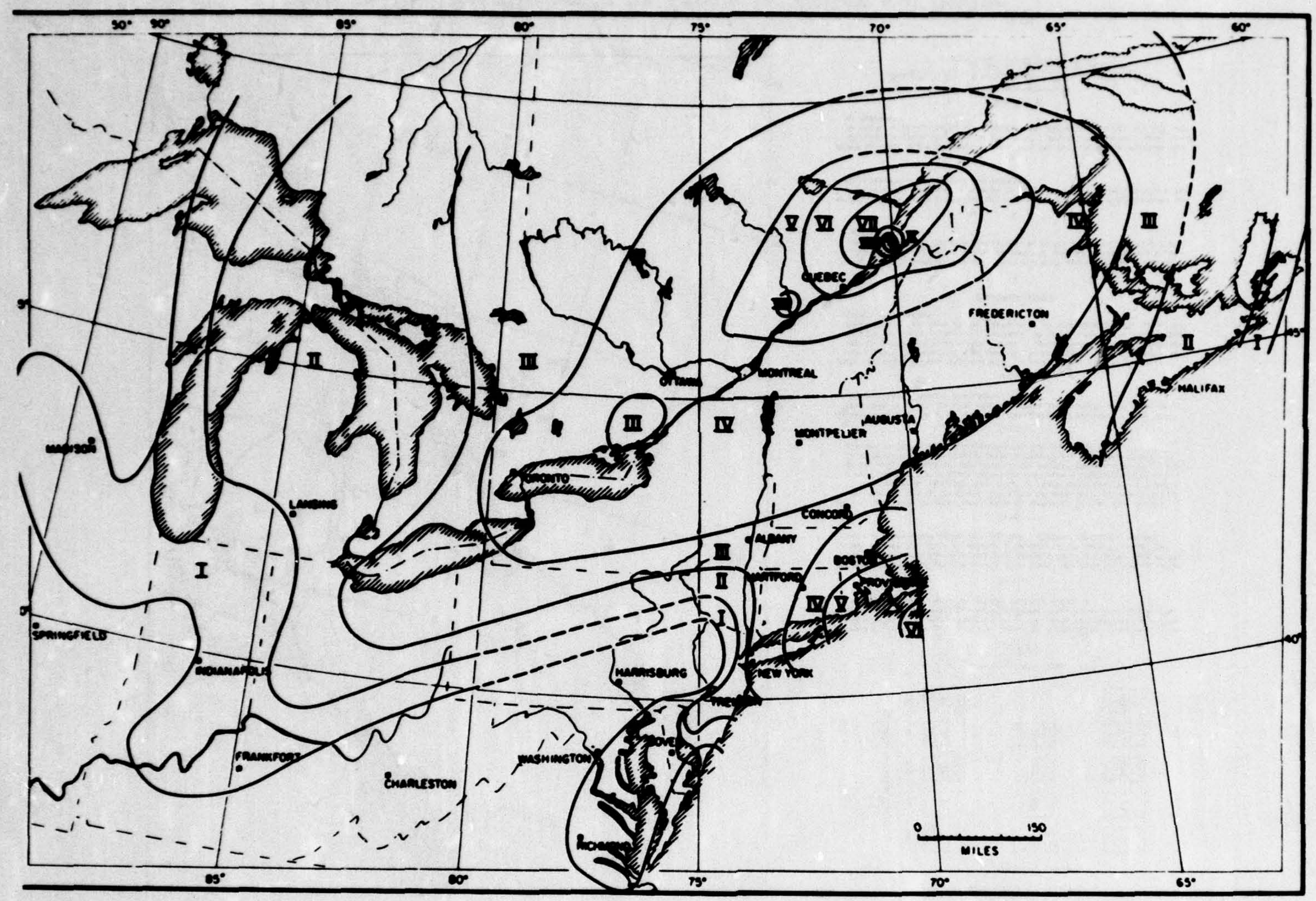


Figure 17. Isoseismal pattern for the St. Lawrence earthquake of March 1, 1925 (NEIS)

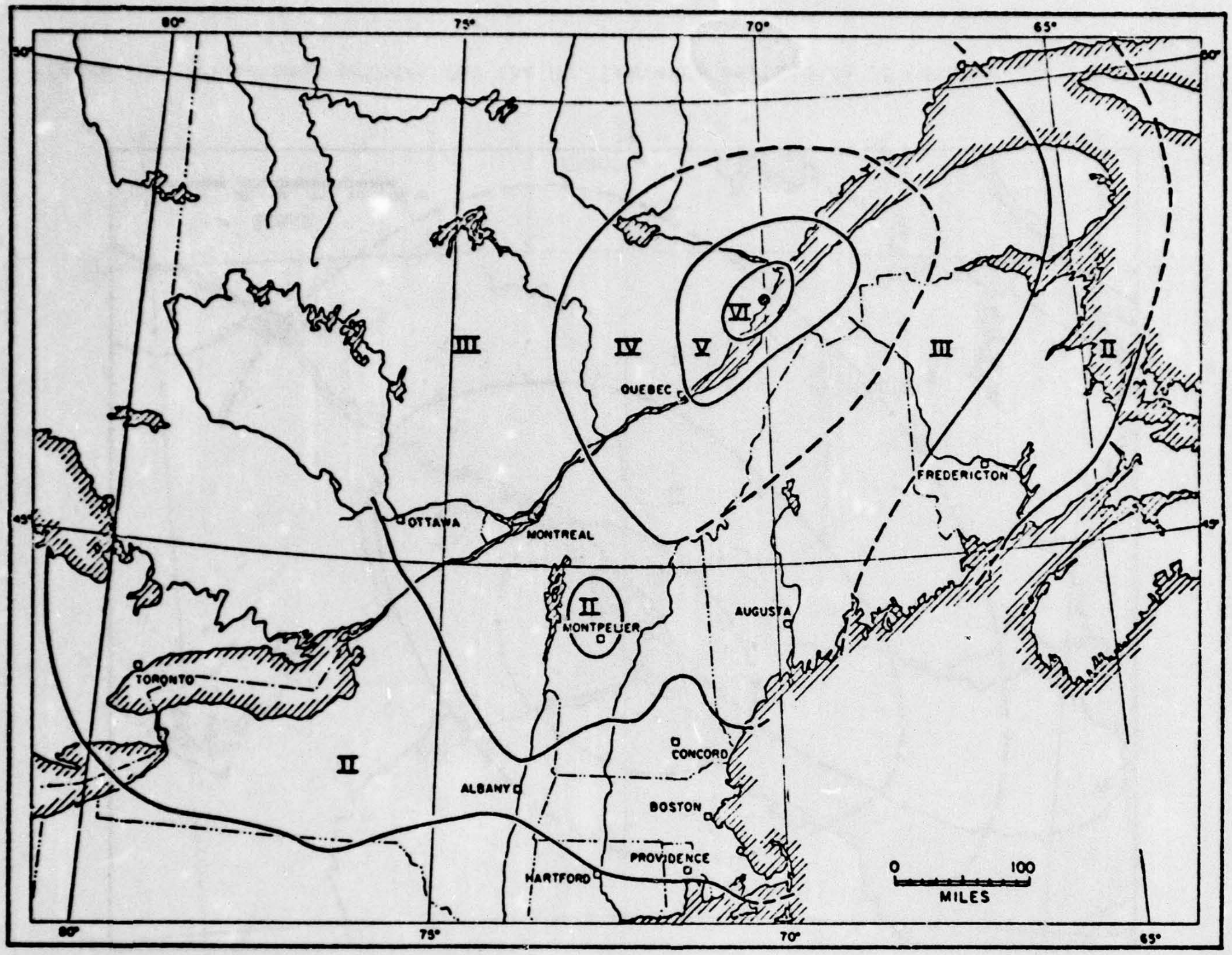


Figure 18. Isoseismal pattern for the St. Lawrence earthquake of October 19, 1939 (NEIS)

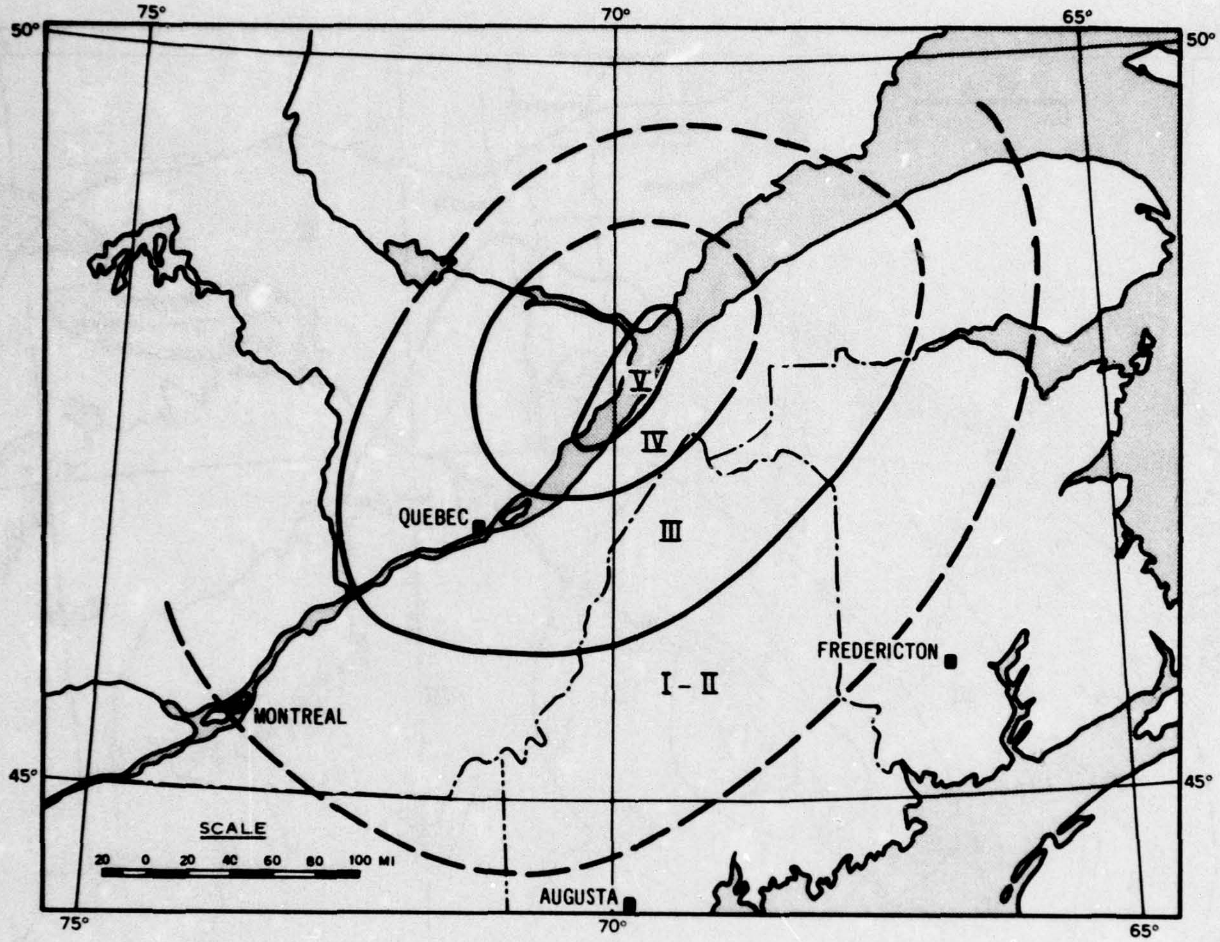


Figure 19. Isoseismal pattern for the St. Lawrence earthquake of October 14, 1952 (NEIS)

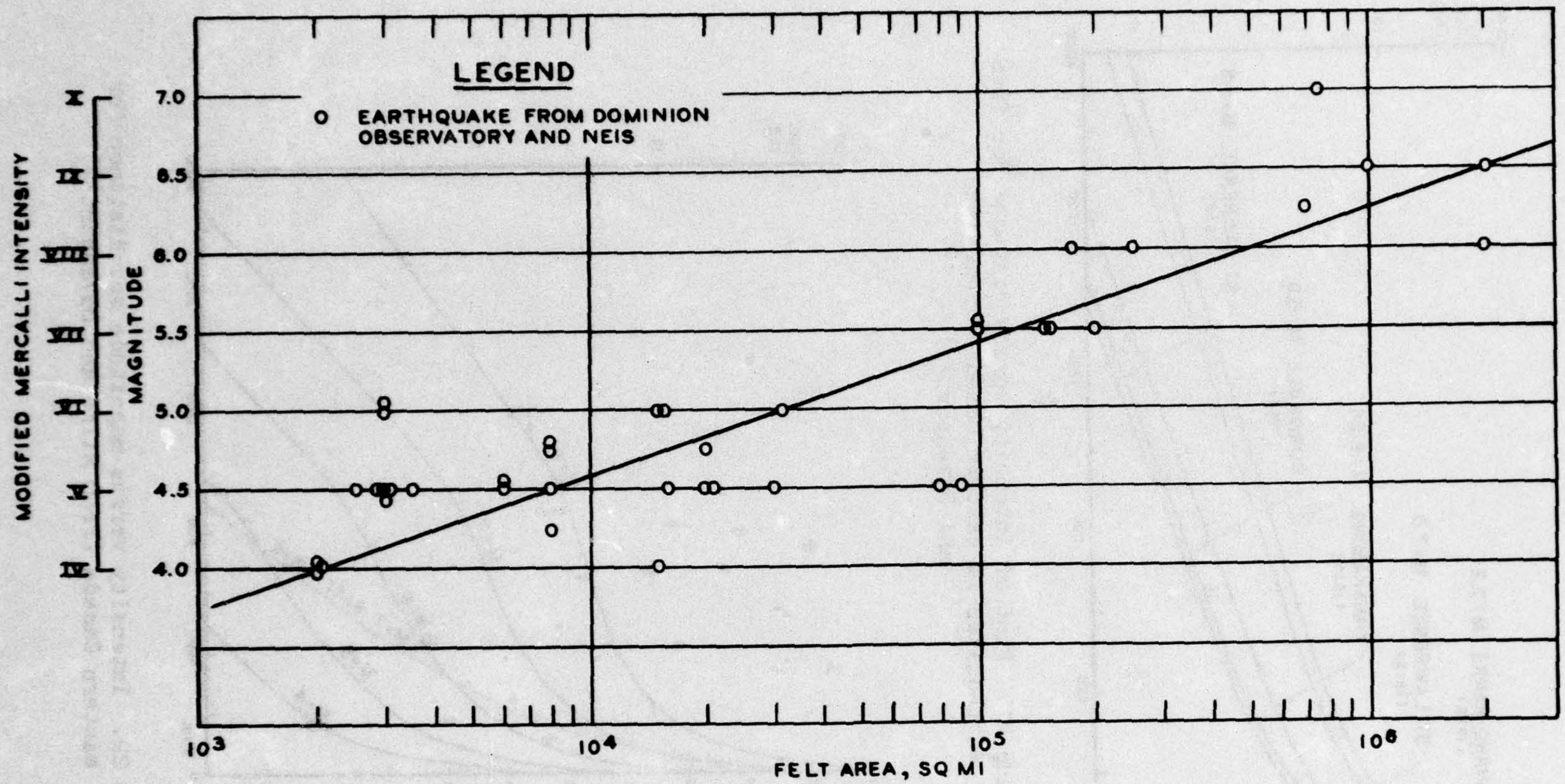


Figure 20. Relation between intensity, magnitude, and felt area in northern New England and adjacent parts of Canada

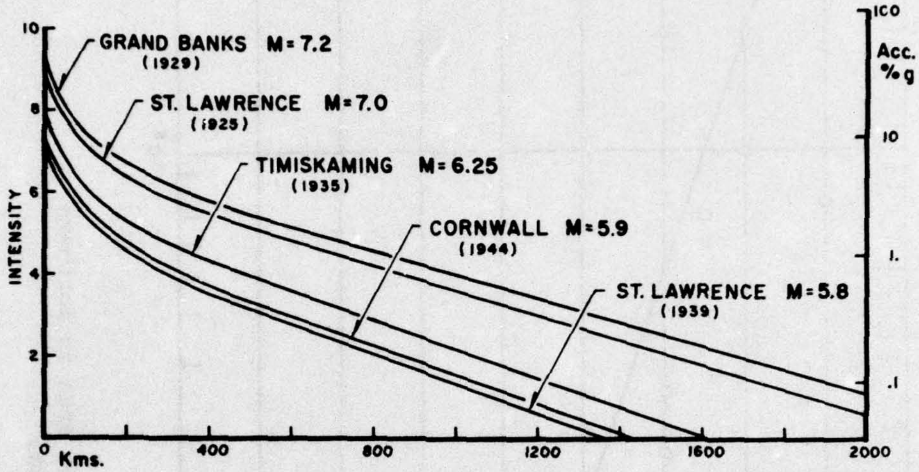


Figure 21. Plot of intensity versus distance for five earthquakes in eastern Canada (from Milne and Davenport[19])

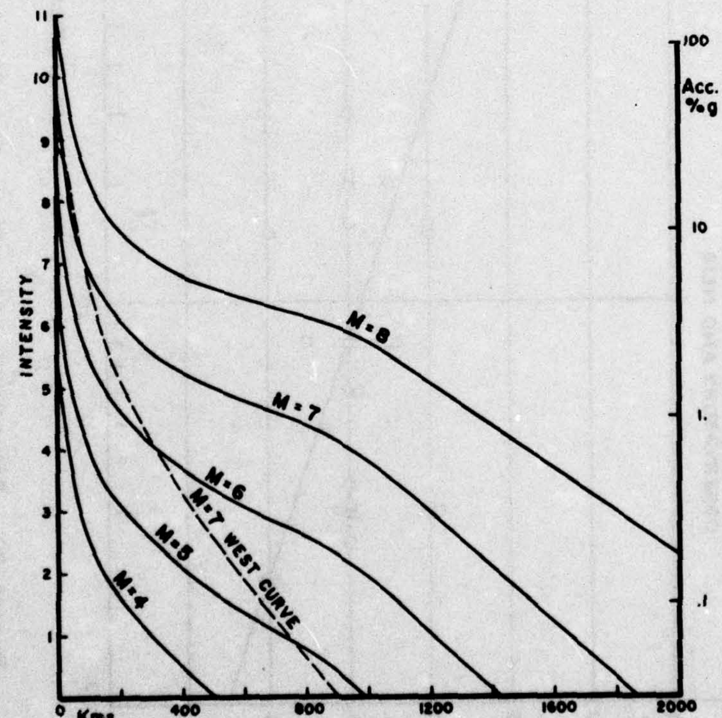


Figure 22. Intensity versus magnitude and distance for eastern Canada (from Milne and Davenport[19])

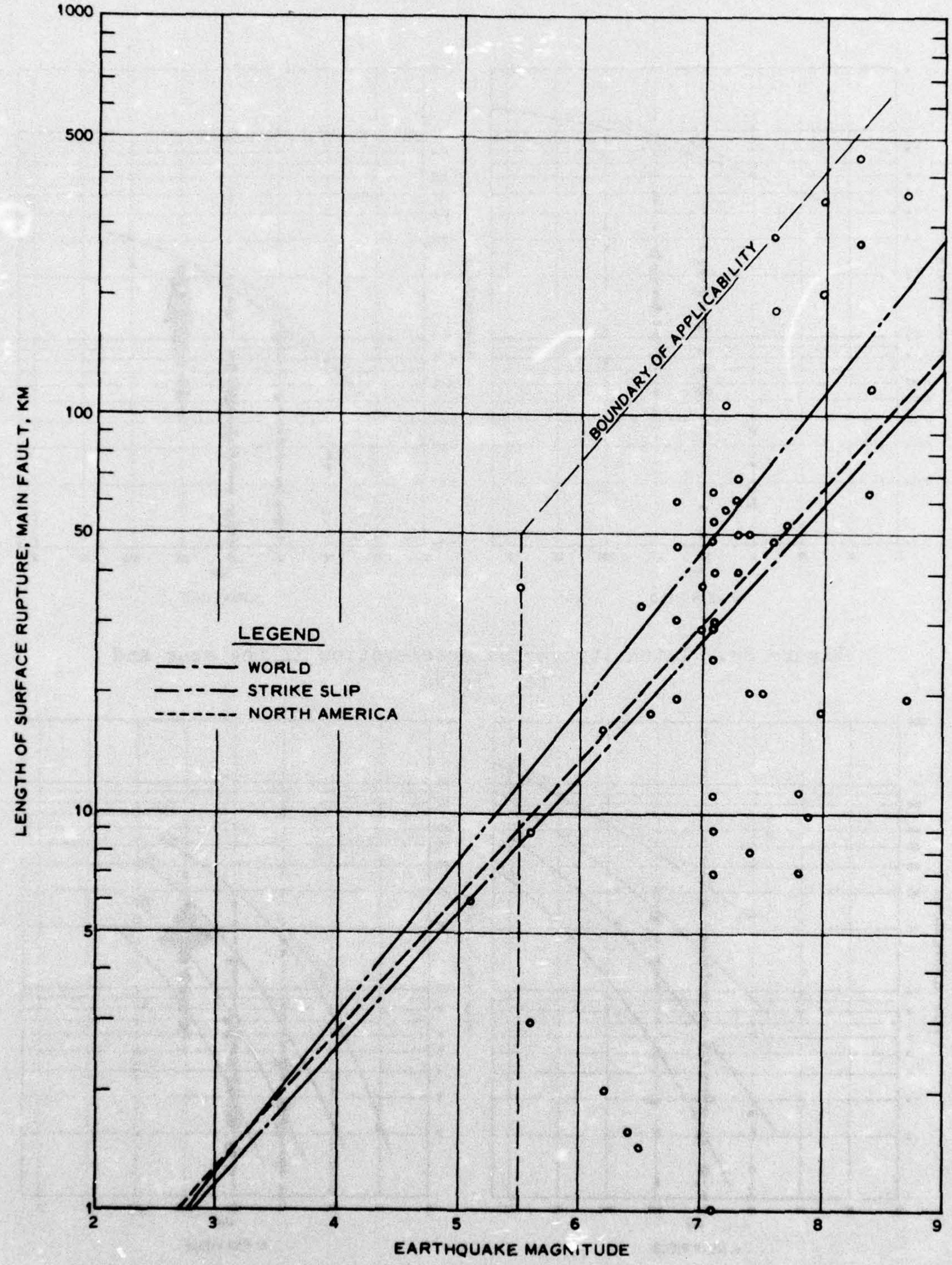


Figure 23. Length of surface rupture on main fault as related to earthquake magnitude (from Bonilla and Buchanan[20]); the boundary of applicability has been added

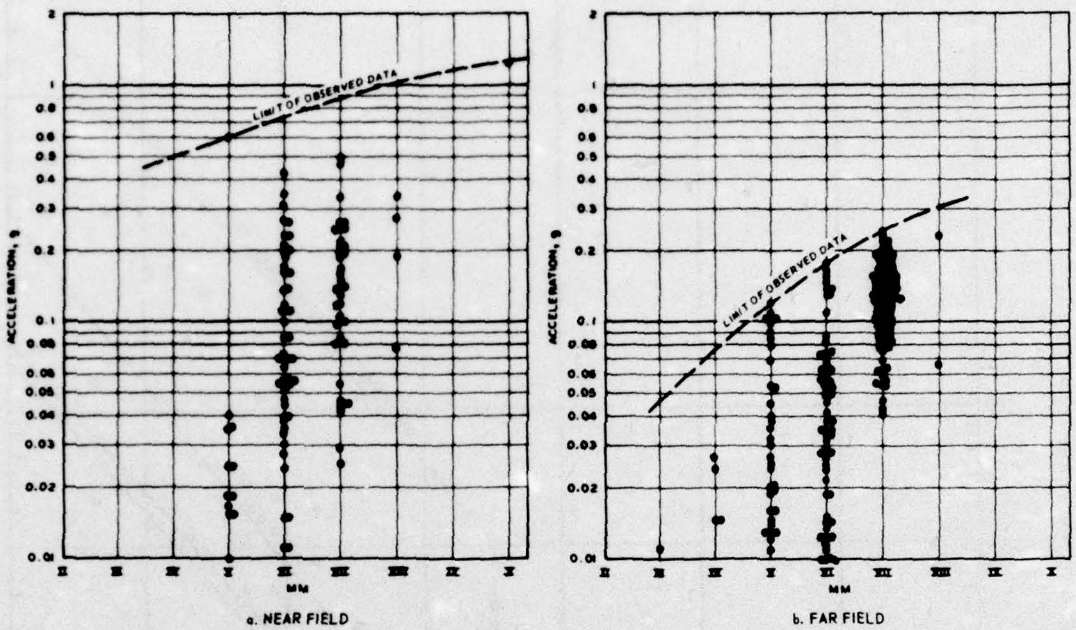


Figure 24. Intensity versus acceleration in the near and far fields

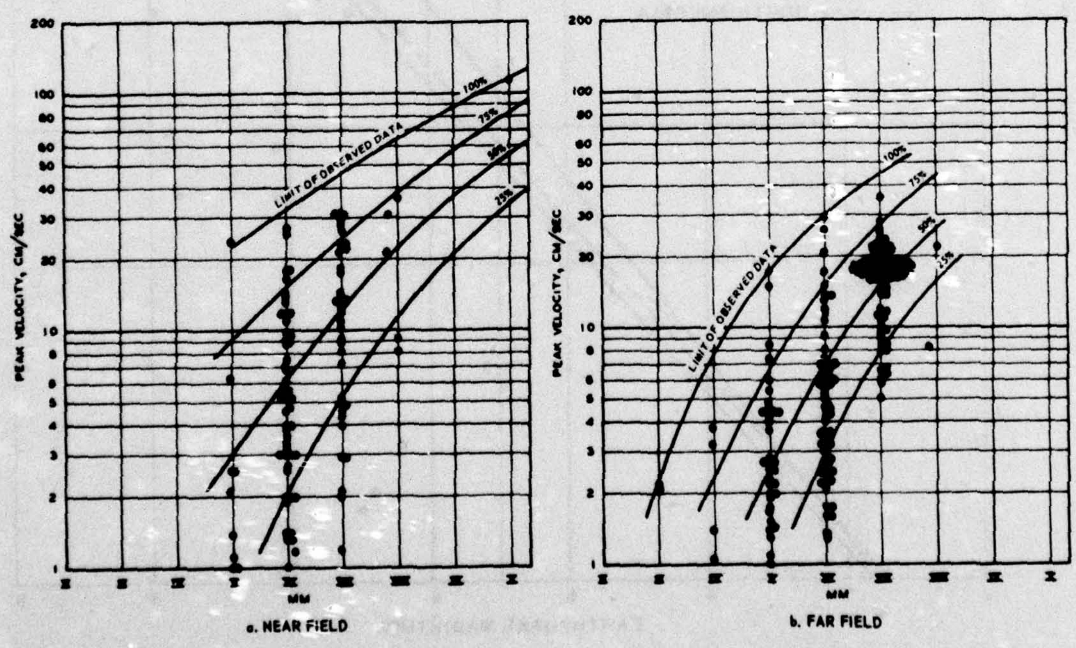


Figure 25. Intensity versus velocity in the near and far fields

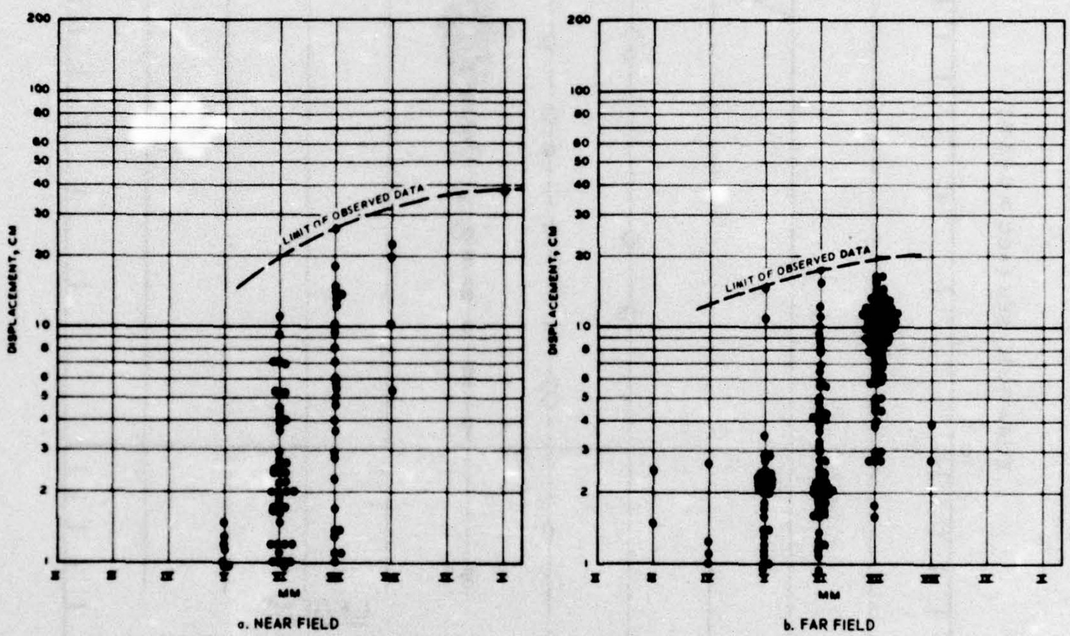


Figure 26. Intensity versus displacement in the near and far fields

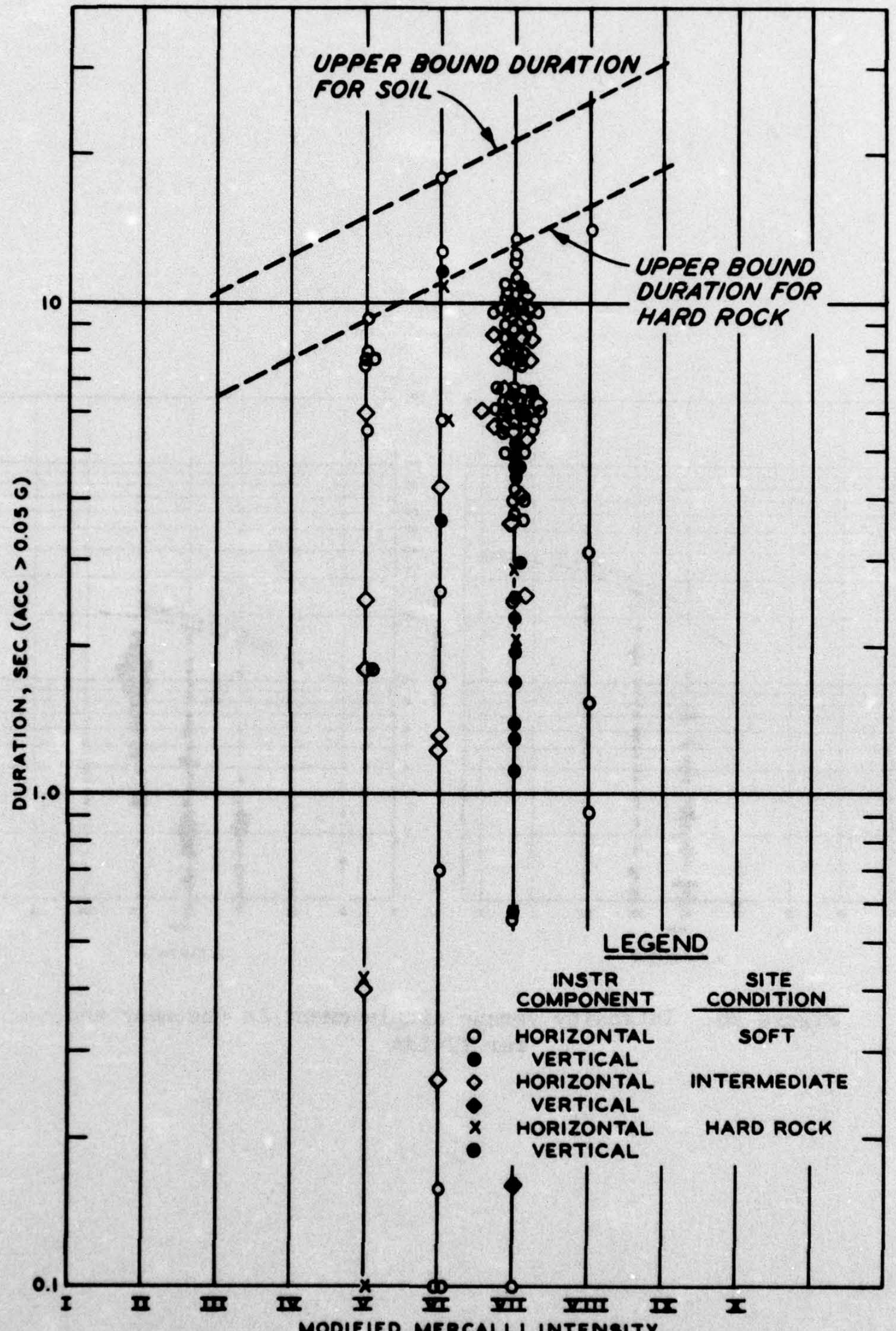


Figure 27. Relation of intensity to duration in the far field (Chang[21])

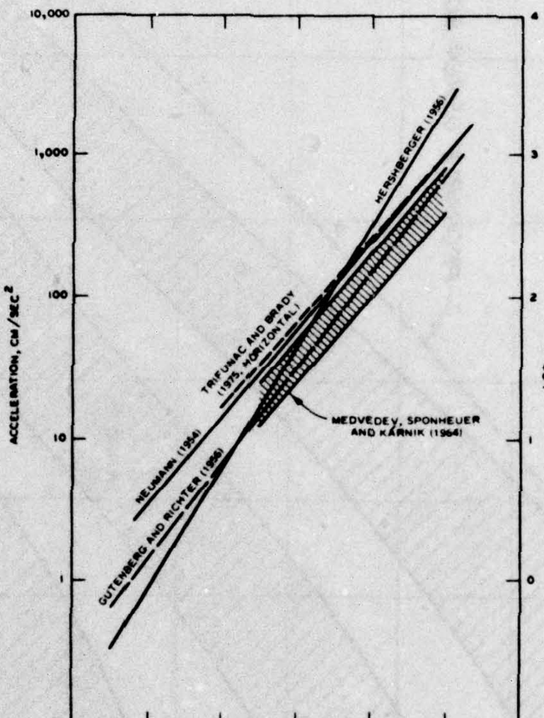


Figure 28. Commonly used correlations between intensity and acceleration

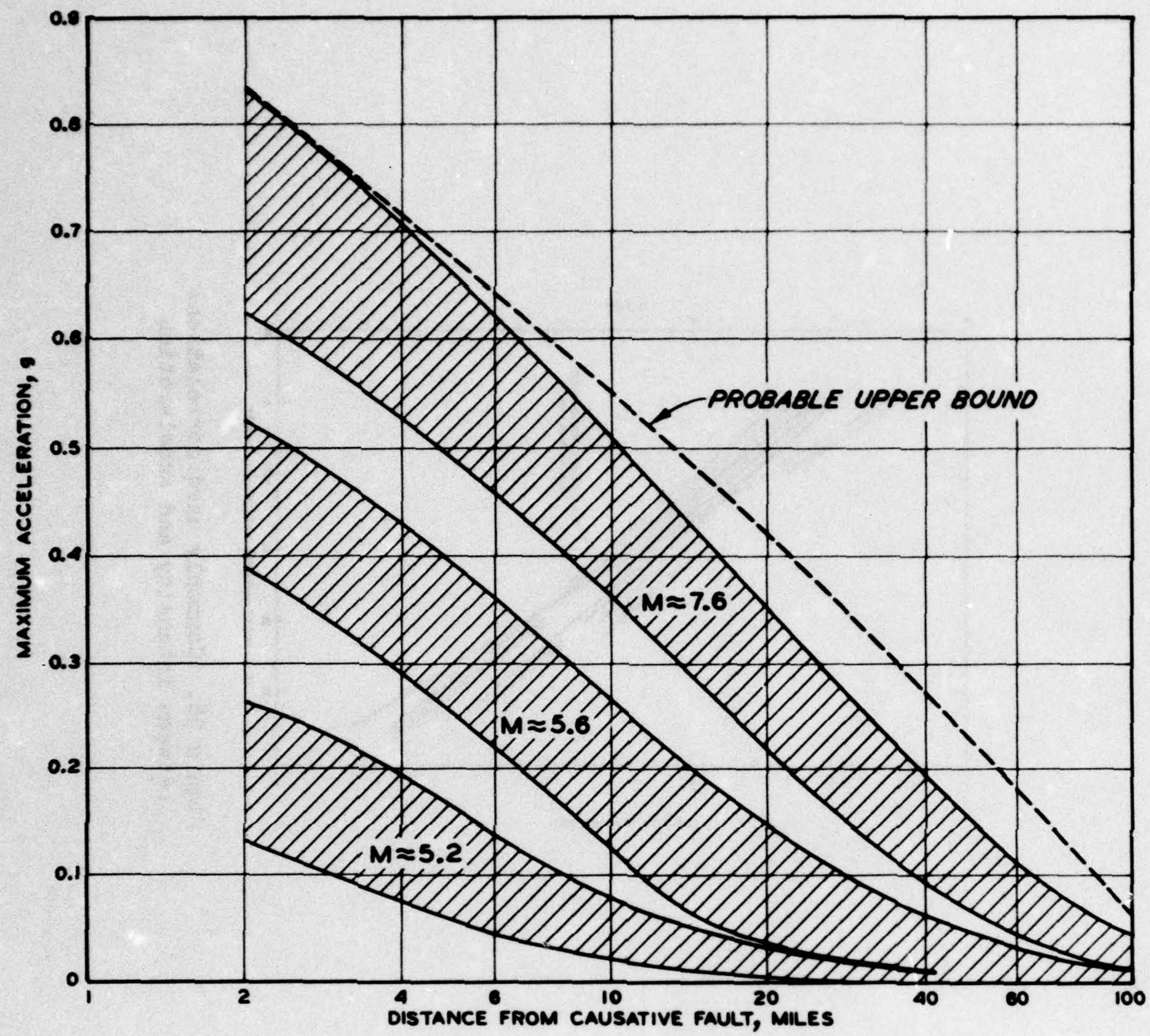


Figure 29. Ranges of maximum accelerations in rock for the western United States (from Schnabel and Seed[28])

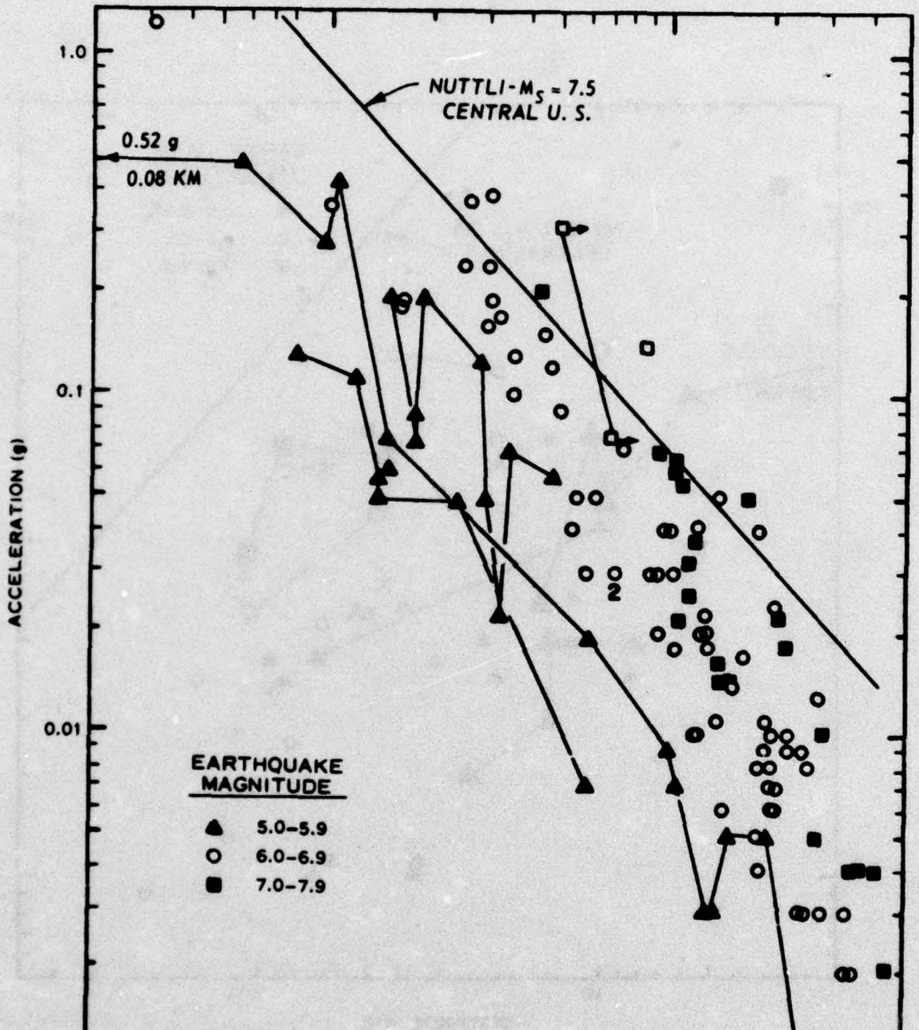


Figure 30. USGS accelerations for western United States earthquakes (Page et al.[29]) with Nuttli's[27] predictions for the central United States

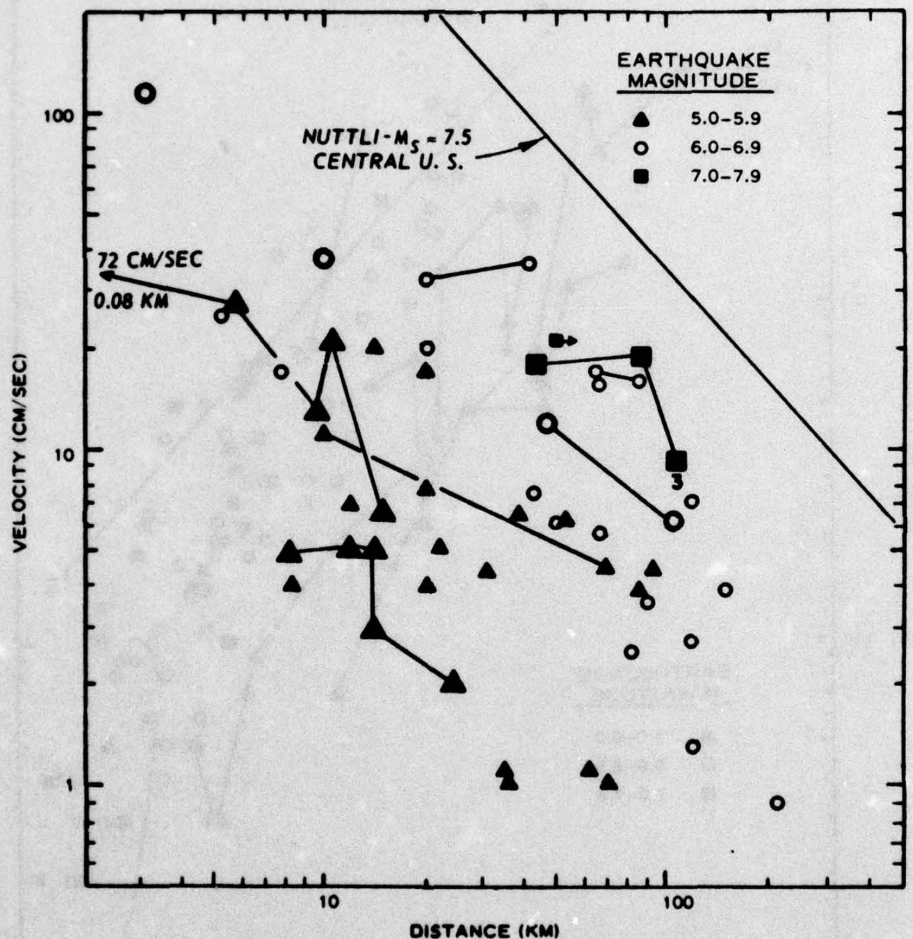


Figure 31. USGS particle velocities for western United States earthquakes (Page et al.[29]) with Nuttli's[27] predictions for the central United States

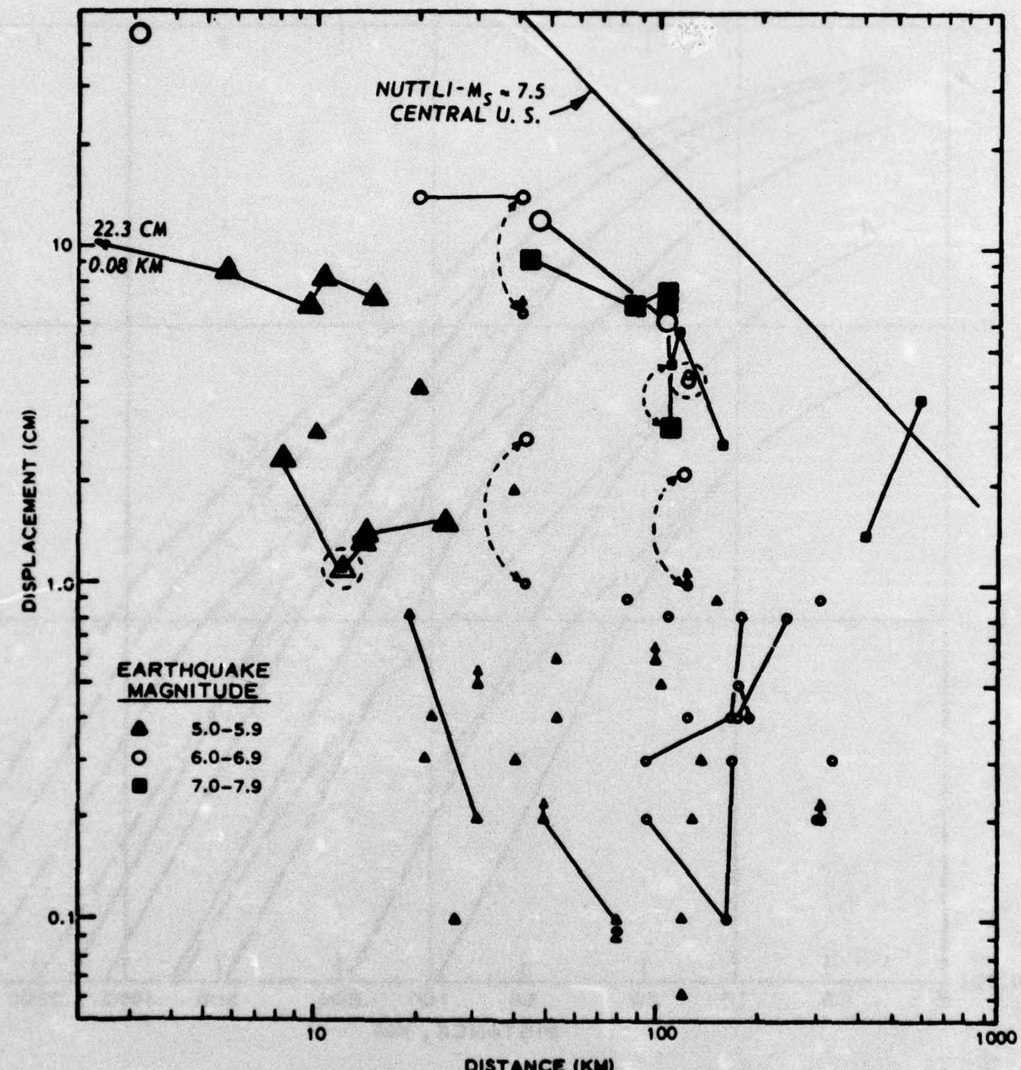


Figure 32. USGS displacements for western United States earthquakes (Page et al.[29]) with Nuttli's[27] predictions for the central United States

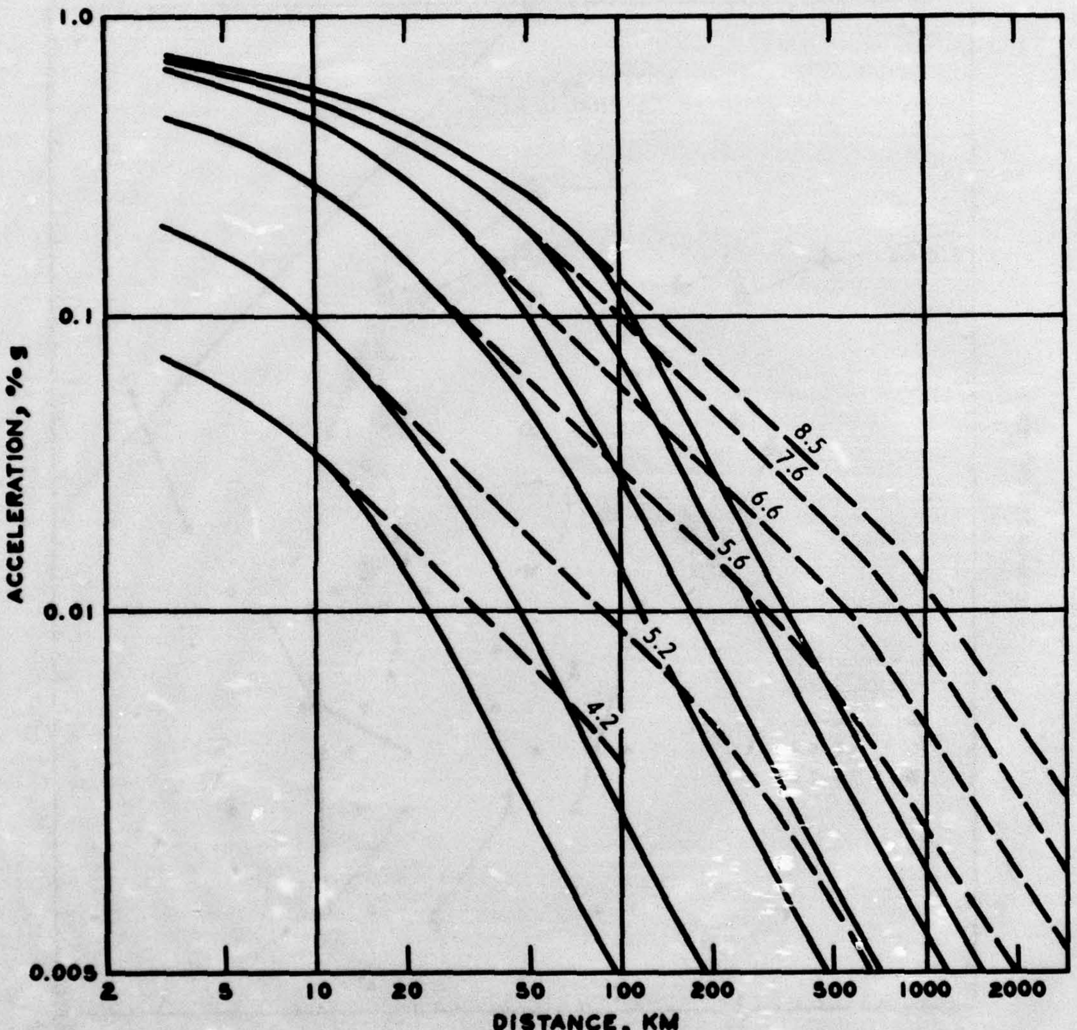


Figure 33. USGS[30] accelerations for the eastern United States (solid lines). The lines are those of Schnabel and Seed[28] and were modified (dashed lines) by imposing the attenuations of Nuttli[27] for the central United States

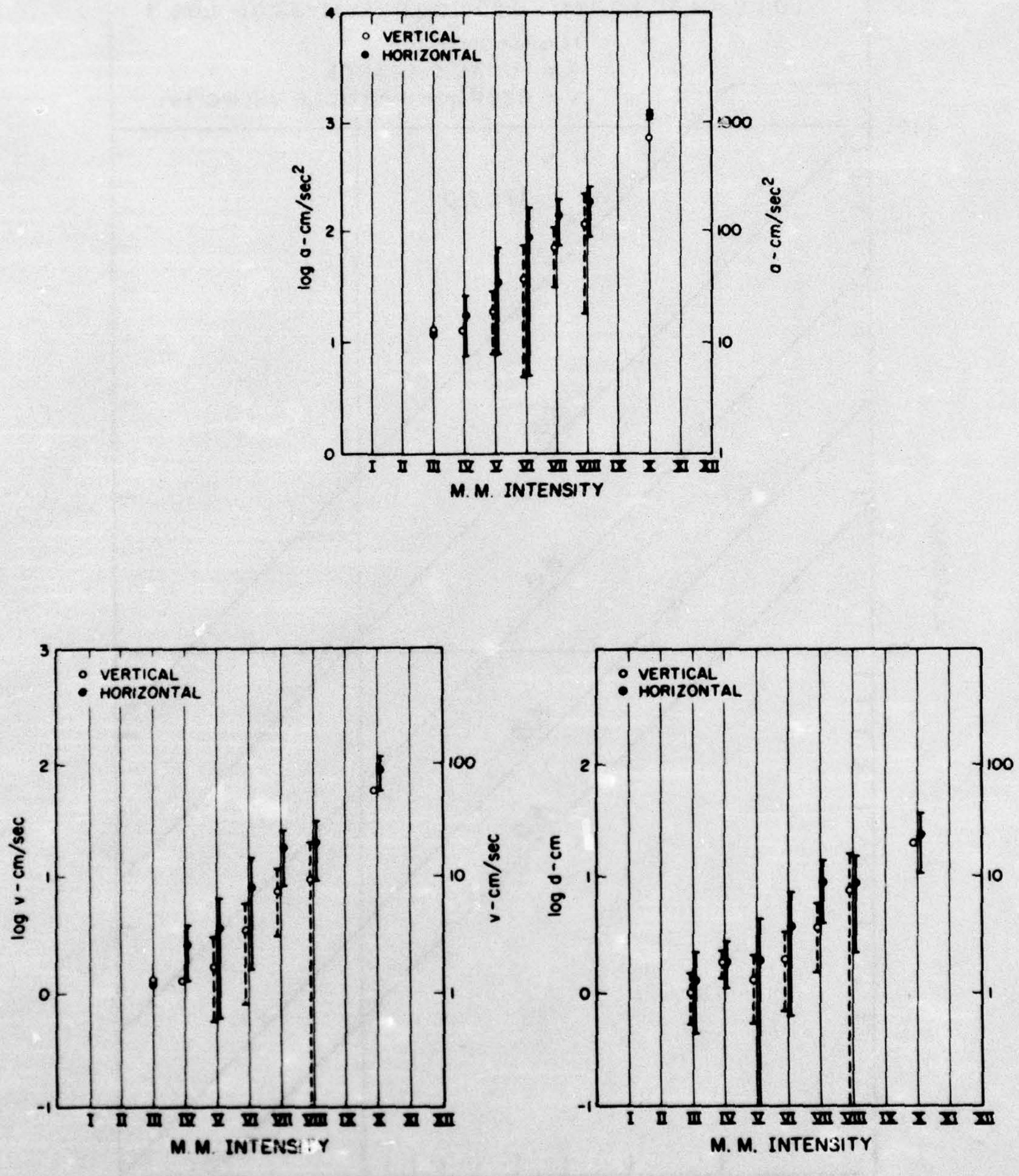


Figure 34. Ground motions versus intensity for the western United States by Trifunac and Brady.[26] Means (vertical and horizontal) plus one standard deviation are shown for (a) acceleration, (b) velocity, and (c) displacement

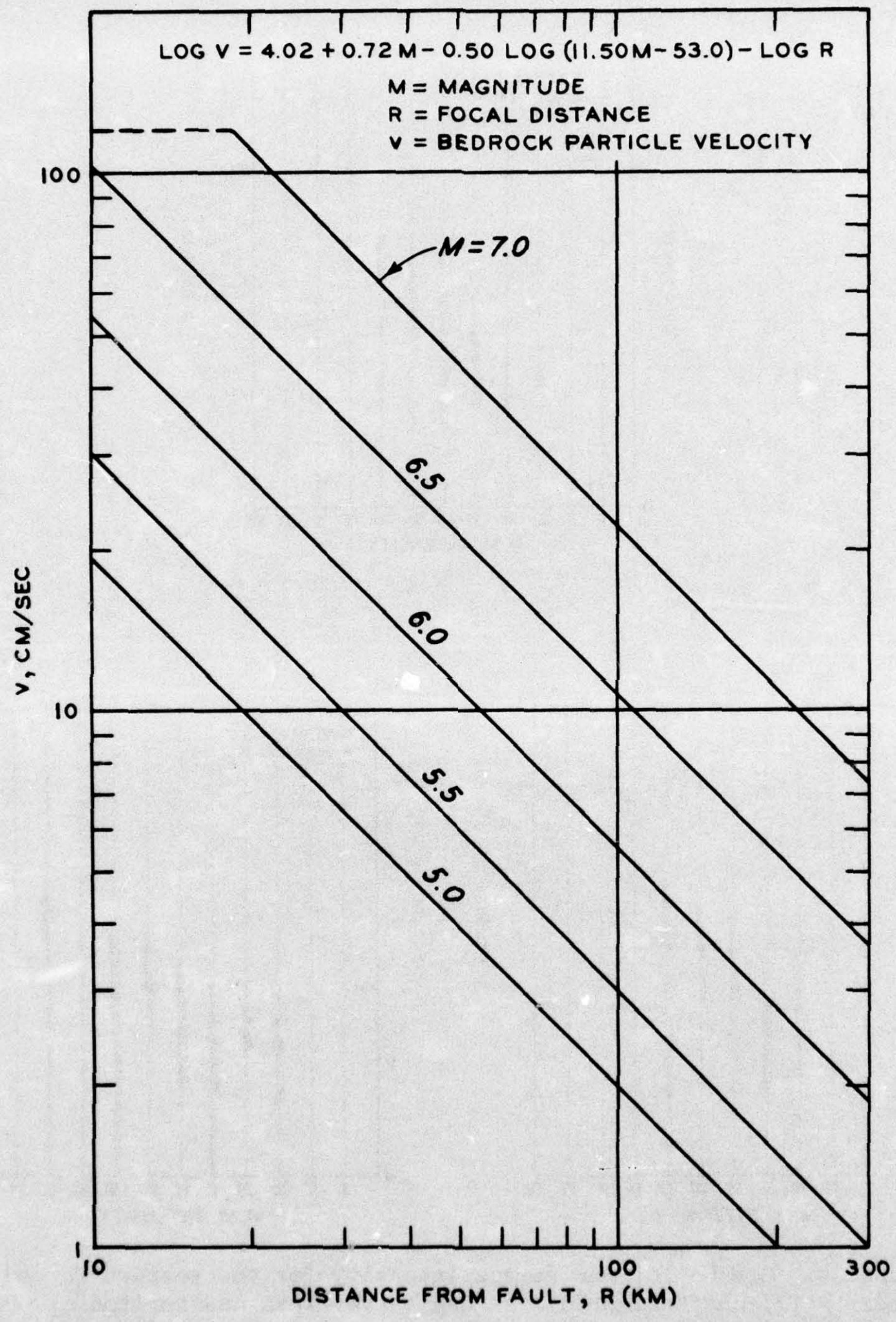


Figure 35. Maximum probable ground velocities by Ambraseys (from Johnson and Heller[31])

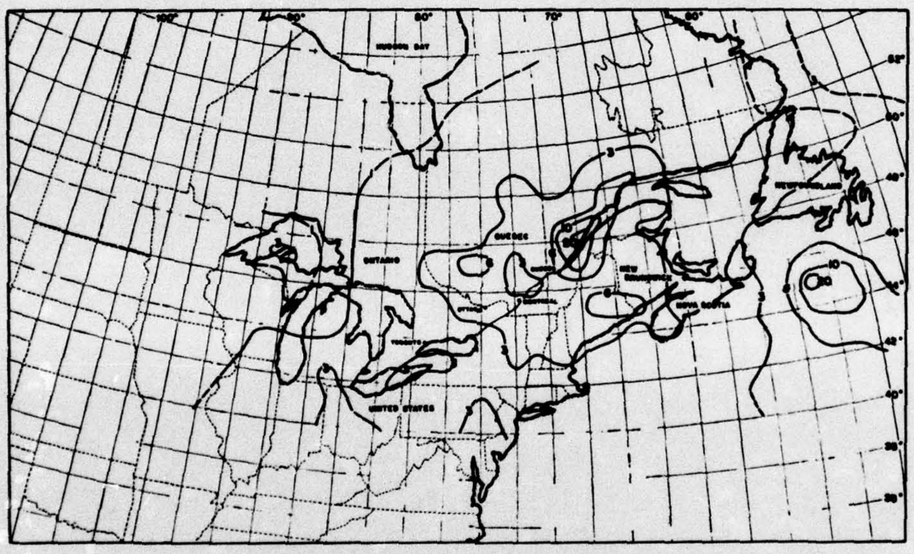


Figure 36. Accelerations as a percent of g with a 100-year return period for eastern Canada (after Milne and Davenport[19])

APPENDIX A: LETTERS FROM CONSULTANTS

Dr. David B. Slemmons
Consulting Geologist

Dr. Otto W. Nuttli
Consulting Seismologist

DAVID B. SLEMMONS
MACKAY SCHOOL OF MINES
UNIVERSITY OF NEVADA
RENO, NEVADA 89507

September 16, 1975

This letter reports on my study of the report by Ellis L. Krinitzsky and David M. Patrick on the "Dickey-Lincoln School Damsites, Maine". The results of their study were discussed at a conference at Vicksburg, Mississippi on September 16, 1975 and the Earth Resources Technology Imagery (ERTS) of the region was also reviewed.

This study is based on a special field and imagery search for active faults. No active surface faults were identified near the siting area or along the St. Lawrence Seismic Belt. My evaluation of the ERTS images corroborated the lack of any evidence of active surface faulting in this region.

The broad floor of the St. Lawrence River Valley, about 40 miles north of the siting area, has high historic seismicity with two large earthquakes of over 7 magnitude. The lack of surface faults may be due to the recency of deglaciation and the extensive cover of water and recent alluvium. The historic seismic record defines the narrow St. Lawrence Seismic Belt, which has great length and continuity (Zone A) and a sharp drop-off in frequency and magnitude of earthquakes on the southern edge of the St. Lawrence Valley (Zone B) into the stable Upland province near the site (Zone C). Zone D, a zone of higher activity, borders Zone C on the south.

I concur with the seismotectonic zoning of their report and believe that the design earthquakes are conservative and realistic for this region, and are compatible with the historic earthquake record.

Signed: David B. Slemmons
Consulting Geologist

OTTO W. NUTTLI
SAINT LOUIS UNIVERSITY
SAINT LOUIS, MISSOURI 63156

September 16, 1975

I am commenting on the seismological portions of "Earthquake Investigations at the Dickey-Lincoln School Damsites, Maine, Part I. Geological and Seismological Factors and the Selection of Design Earthquakes" by E. L. Krinitzsky and David M. Patrick.

On the basis of the historic seismicity (presented in Figure 4 of the report), I agree with the division of the region into 4 zones whose boundaries more or less parallel the boundaries of the St. Lawrence River. The authors' selection of maximum credible earthquakes (as presented in Table 4) for the 4 zones is reasonable. These maximum credible earthquakes in all four cases are of magnitude and epicentral intensity greater than that of any earthquakes which have occurred since 1600.

The quantitative relations used by the authors for attenuation of intensity with distance, and of values of ground acceleration, velocity, displacement, and duration as a function of intensity conform to the present state-of-the-art.

The values given in Table 7 are the important ones for the design of the dam. The authors of the report have considered the various methods currently used by earthquake engineers and seismologists in arriving at design values, and those which they present in Table 7 are conservative, but in a realistic sense, design parameters.

As can be seen from Table 7, the largest motions which the dams can be expected to undergo correspond to those from a Zone A type earthquake. Strong-motion records which may be scaled up to represent the ground motions at the damsites are:

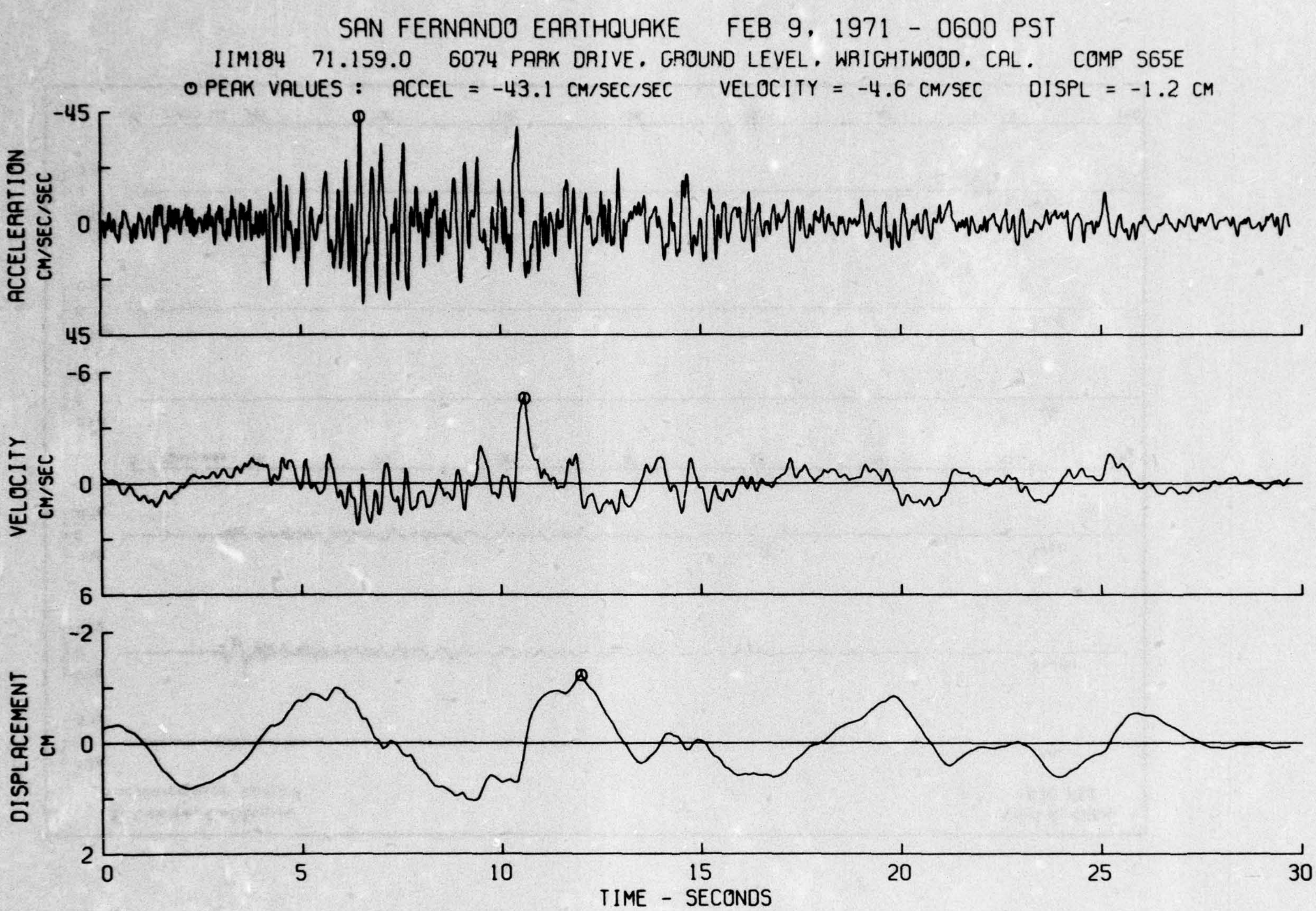
Earthquake	Accelerograph Location	Epicentral Distance	Magnitude	Site Intensity	Peak Acceleration
San Fernando, Calif., Feb 9, 1971	Wrightwood, Calif. #9003	70 km	6.5		0.05 g
El Centro, Calif. Apr. 8, 1968	El Centro, Imperial Valley Irrigation District Station	41 miles	6.5		0.12 g
Northern Utah Aug. 30, 1962	Logan, Utah	46 miles	5.7	VII	0.11 g

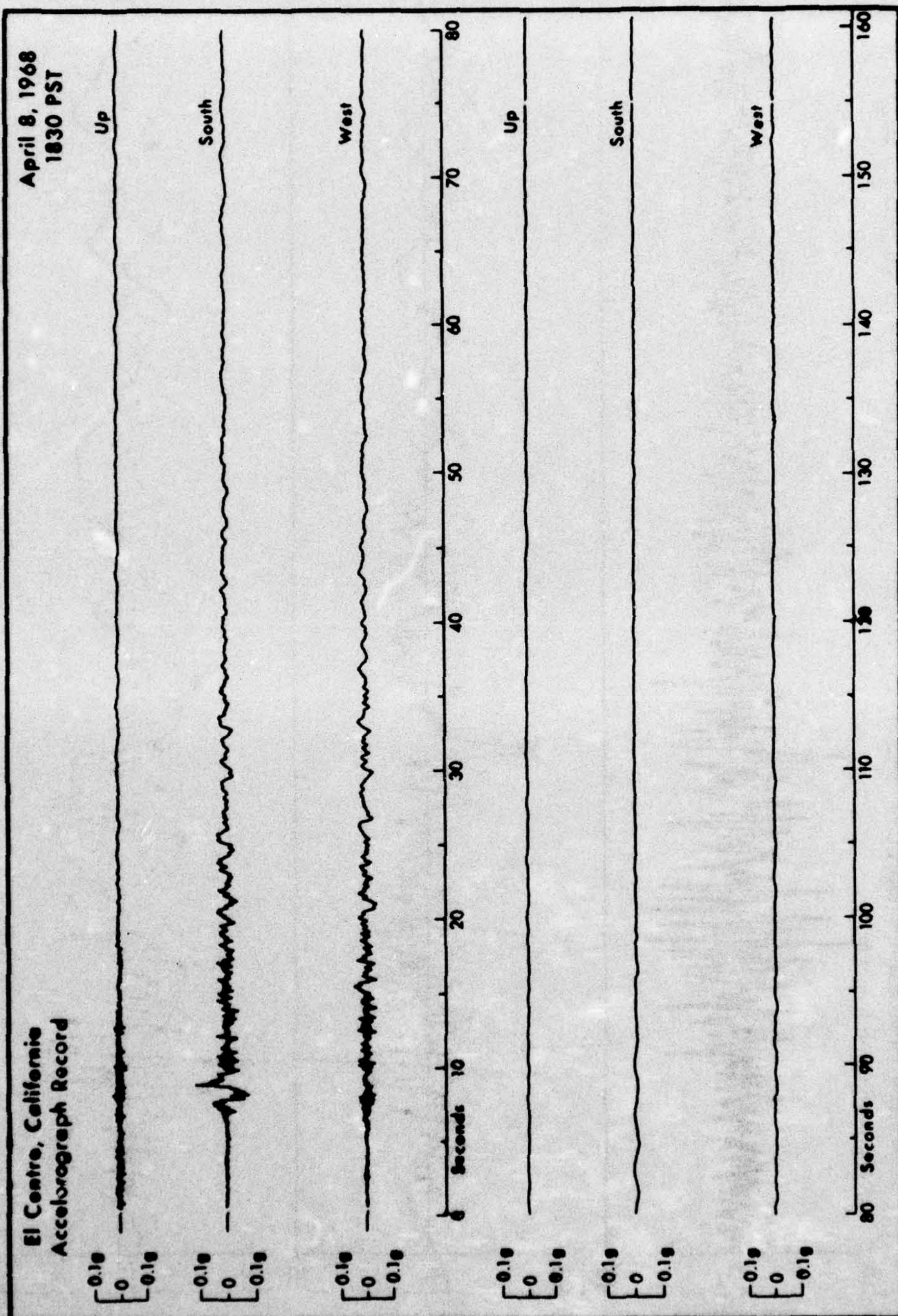
An accelerogram which can be scaled up to represent Zone C earthquake is:

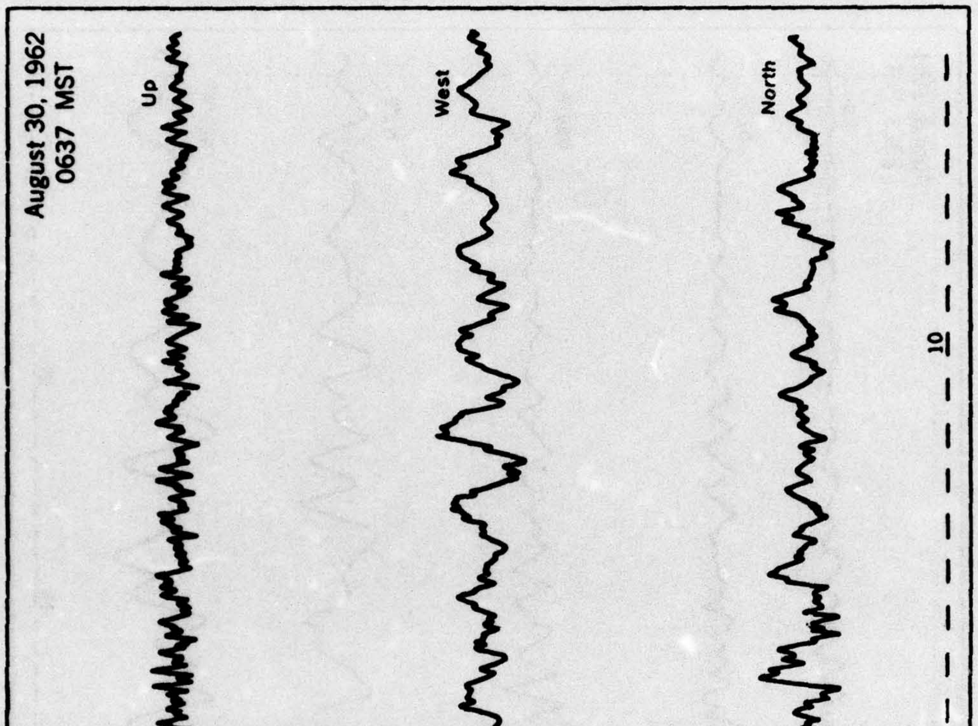
Hollister, Calif. Apr 8, 1961	Hollister, Calif.	13 miles	5.6	VI	0.16 g

Copies of the accelerograms are attached.

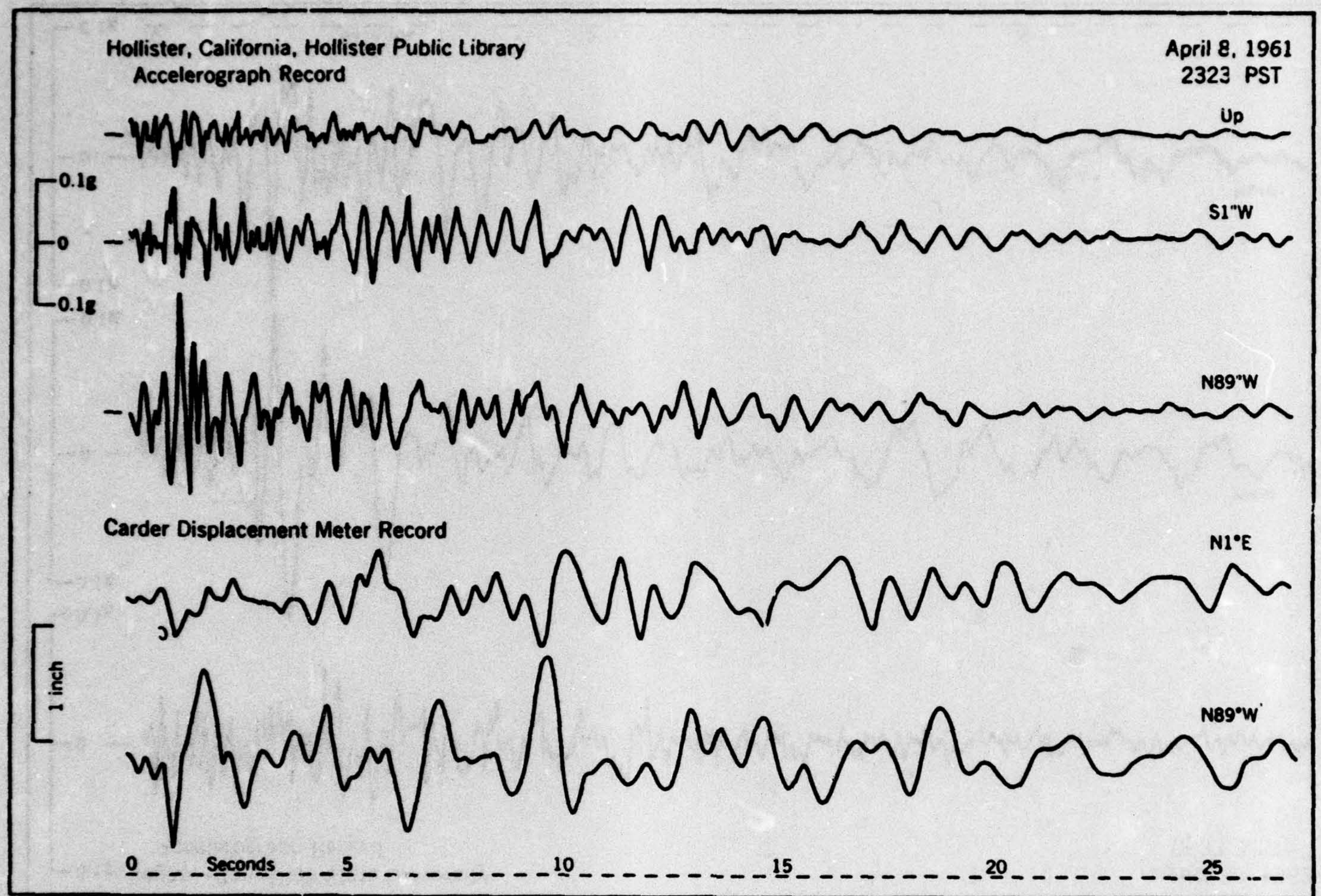
Signed: Otto W. Nuttli
Consulting Seismologist


SAN FERNANDO EARTHQUAKE FEB 9, 1971 - 0600 PST
IIM184 71.159.0 6074 PARK DRIVE, GROUND LEVEL, WRIGHTWOOD, CAL. COMP S65E
⊙ PEAK VALUES : ACCEL = -43.1 CM/SEC/SEC VELOCITY = -4.6 CM/SEC DISPL = -1.2 CM
ACCELERATION CM/SEC/SEC
-45
0
45
VELOCITY CM/SEC
-6
0
6
DISPLACEMENT CM
-2
0
2
0
5
10
15
20
25
30
TIME - SECONDS


El Centro, California
Accelerograph Record
April 8, 1968
1830 PST
Up
South
West
0.1g
0
0.1g
Seconds
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160



Logan, Utah, Utah State University
Accelerograph Record
August 30, 1962
0637 MST
Up
West
North
0.1g
0
0.1g
Seconds
0
5
10


Hollister, California, Hollister Public Library
Accelerograph Record
April 8, 1961
2323 PST
Up
S1°W
N89°W
0.1g
0
0.1g
Carder Displacement Meter Record
N1°E
N89°W
1 inch
0
Seconds
5
10
15
20
25

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Krinitzsky, Ellis Louis
Earthquake investigations at the Dickey-Lincoln School damsites, Maine, by Ellis L. Krinitzsky and David M. Patrick. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1977.
1 v. (various pagings) illus. 27 cm. (U. S. Waterways Experiment Station. Miscellaneous paper S-77-2)
Prepared for U. S. Army Engineer Division, New England, Waltham, Massachusetts.
Includes bibliography.

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TA7.W34m no.S-77-2